EVALUATION OF GRAIN LOSSES AND GRAIN DRYING PERFORMANCE AT LARGE GRAIN STORAGE AND HANDLING FACILITIES IN A DEVELOPING COUNTRY (SOME CNP OPERATIONS IN COSTA RICA)

by

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INTRODUCTION

The opportunity to develop this project must be considered unique because of the opportunity to directly assess postharvest grain losses of white corn (dry season crop, 1987) in large-scale elevators in Costa Rica. There is no evidence that a similar study has ever been done in a developing country.

The 1975 Resolution of the VIIth Special Session of the United Nations General Assembly committed the member states to reducing post-harvest food losses by 50 percent by 1985. The reason was simple. For many years, efforts to increase the world's food supply were concentrated in the area of production only. Some success was attained with the so-called "Green Revolution" which brought substantial improvements in seeds, fertilizers, and crop yields, among others. However, the neglected dimension in the world's attempt to increase the food supply was always the possible reduction of food losses that occur between harvest and consumption, which are considered to be quite high (for planning purposes, the figures used are 10 percent for cereal grains and grain legumes and 20 percent or higher for nongrain staples and other perishables, including fish[1]). If we consider the fact that in some parts of the world, the grain production rate has not been proportional to the rate of population growth, the problem of food loss prevention becomes even more important. The following figures can help us to understand the implications of this last statement. In 1984, the world's population

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[1] National Academy of Sciences, 1978.

was 4.5 billion people and the total grain production was 1.8 billion MT[1]. Assuming that a person fed only with grain would require 220 kg per year, the theoretical world need would be 1 billion MT, a figure smaller than the actual total grain production. In reality, however, the situation is different for four main reasons: an uneven grain distribution, the use of part of the grain for animal feed, the use of part of the grain for industrial purposes, and the occurrence of grain losses (in weight and quality). If we assume that the grain losses in 1984 were 10 percent, the net loss would be 180 million MT (enough to feed 818 million people for 1 year) with an approximate value of $18 billion (assuming $100/MT). Therefore, the main benefits to be derived from improving postharvest grain systems in order to reduce losses and maintain quality are:

1. Increase the availability of grain supply.
2. Increase the income of farmers and their economical status.
3. Supply good quality grain to consumers.
4. Use currency for other development programs.
5. Create jobs - potential for agroindustrial enterprises.

Within this framework, it is easier to understand why the Costa Rican government sought financial support from the United States Agency for International Development (USAID) to start a study on postharvest grain losses at all levels, with technical support from experts of the Food and Feed Grains Institute (FFGI) at Kansas State University (KSU). The study was to be conducted by the Centro para Investigaciones en

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[1] 1984 FAO Production Yearbook, 1986.

Cranos y Semillas (CIGRAS). The Consejo Nacional de Producción (CNP), a government agency in charge of the large-scale postharvest handling and storage of corn, beans, and imported wheat, was included in the study because of its crucial role in the postharvest chain. Normal operations of CNP are, among others:

1. Buy the grain from farmers at local purchasing agencies.
2. Transport the grain from purchasing agencies to regional elevators.
3. Clean, dry, and store grain at the elevators.
4. Keep grain in good condition during storage until it is sold.

Food losses are related as much to social phenomena as to physical and biological factors. Cultural attitudes and practices form the critical inescapable backdrop for postharvest operations and loss reduction activities[1]. This reality was well understood by Dr. Do Sup Chung, Professor, Food and Feed Grains Institute, Kansas State University, and director of this project, who chose a Costa Rican engineer from CNP to carry on the research as a part of his Master's program in agricultural engineering.

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[1] National Academy of Sciences, 1978.

OBJECTIVES

The objectives of this study were the following:

1. Review known grain loss assessment methodologies.
2. Select grain loss assessment methods to be used.
3. Evaluate grain losses (weight and quality changes) during normal grain handling, drying, and storage operations at a few selected CNP facilities.
4. Analyze grain cleaning and drying operations with respect to grain quality (clean and unclean grain), thermal efficiency, and costs in Costa Rica and Clay Center, Kansas.
5. Analyze the results.
6. Develop grain loss reduction strategies.

LITERATURE REVIEW

Grain Loss Assessment

During the last 12 years, there has been a strong worldwide initiative to develop and improve postharvest loss prevention methods. However, there is still a lack of information in many areas, and an accurate estimation of grain losses is very seldom found. Harris and Lindblad (1978) stated that determination of losses to food crops requires careful blending of the concepts and procedures of several sciences, with each given its necessarily detailed attention. In this sense, the National Academy of Sciences (1978) established that it is very difficult to estimate postharvest food losses with precision, partly because of their inherent variability, but also due to the many cultural and economic factors that frustrate the smooth, efficient flow of food through the postharvest system from producer to consumer.

Assessment, Measurement, and Estimation

These terms are used in the literature to describe different kinds of processes that determine losses with varying degrees of confidence.

Assessment is used to denote the rough quantitative approximation of food loss or to characterize the relative importance of different points of loss in a particular food chain. Implicit in the use of this term is subjective judgment required because of insufficient information.

Measurement is a more precise and objective process by which quantitative facts about a loss situation are calculated. Implicit in this

process is the belief that the same procedure applied by any observer under the same circumstances will yield the same results. This does not mean that the accuracy of the result is necessarily higher than that of an assessment - the accuracy of the measurement will depend on the method of measurement itself, while the accuracy of an assessment can only be borne out by subsequent measurement.

Estimation is used to describe the process of interpretation of a number of scientific measurements, and thus requires that experience and judgment be brought to bear on the factual information under consideration.

Waste and wastage are terms included here because they are commonly used in other reports. However, they cannot be precisely defined since they involve subjective and even moral value judgments and depend on the context in which they are used. They should not be used as synonymous with loss and are probably better avoided.

Methodologies for Loss Assessment

Postharvest grain loss assessment methods should yield standardized and reproducible results so that effective grain loss reduction efforts can be undertaken in developing countries (Harris and Lindblad, 1978). The assessment information may provide essential justification and motivation for introducing measures designed to reduce grain losses. The enormous variability of localized postharvest situations indicates that no complete or definite loss assessment methodology for all situations is now possible.

Raboud, Narvaez, and Sieber (1984) described an evaluation method of the post-production losses of basic grains in Honduras (maize, beans, and sorghum) that includes and distinguishes between damages (physical alteration of the grain) and losses (total grain damage minus the grain that is salvaged for consumption). This method uses sampling as a means to show field losses, and monthly sampling to calculate the losses in storage. The sample analysis allows the determination of the level and causes of damages and losses based on the relation between the real and potential weight of the shelled and unshelled sample. The information obtained from the samples (intake and analysis) is complemented through observation and information collected through a questionnaire. The method can also serve as an instrument in technical research and methods of reducing post-production losses.

Cantis (1985 and 1986) directed an FAO study that attempted an evaluation of grain losses at elevators of CNP (the major grain handling agency in Costa Rica) and of the general profile of the technical level of operations. Lack of data and methodological deficiencies did not allow the gathering of quantitative data on grain losses. However, the qualitative information given and the FAO expert's points of view make it clear that CNP needs to improve its operational and technical level, and also that CNP requires efforts in preventing grain losses during handling and storage periods.

Reed (1986) discussed the principal methods of estimating dry weight loss in stored grain and focused on what is known about the precision, accuracy, and limitations of these methods. The information is offered

as an aid to field researchers, and it is hoped they will find it helpful in designing loss surveys, establishing experiment standards (especially related to sample handling and preparation), selecting loss estimation methods, and interpreting the resulting data. The following are the methods to estimate losses in stored grain as described in the report.

"Weigh-in, weigh-out method. This simple technique has been used in laboratory studies of insect activity and grain weight loss since the first experiments of this type. It is the standard against which other loss estimation techniques are compared. Weight losses determined by this method are often called 'observed' losses.

Either in the laboratory or in the field, the moisture content of the grain is taken whenever grain is weighed into or out of the experimental storage container. This is done so that the total weight of dry matter placed under experimental conditions can be compared with the total dry weight of material removed. The dry weight lost during the experiment is then usually expressed as a percentage of the beginning dry weight.

Mean kernel weight (thousand grain mass) method. Mean kernel weight has been used for many years by wheat millers as an indicator of potential flour yield. The development of electronic seed counters in the early 1960s facilitated its use in milling (Johnson and Hartsing, 1963). Baker and Golumbic (1970) found that mean weight (often called thousand kernel weight) was a good indication of milling yield in some classes of wheat, but not in others.

Proctor and Rowley (1983) proposed a method of weight loss estimation, which they called the thousand grain mass (TGM) method, based on changes in the mean kernel weight over time. To use this method, one determines the TGM of a clean sample by weighing and counting the kernels in a randomly selected portion (or duplicate portions) of a grain sample. The moisture content of the grain is determined so that the mean dry weight per kernel can be calculated. The difference between this value, expressed as the dry weight of 1000 kernels, at time A and time B is used to calculate the percent TGM lost. A one-to-one relationship is assumed between the loss of TGM and the loss of total dry weight.

Count and weigh method. Another loss estimation method which utilizes a measure of the mean kernel weight is called the count and weigh (C&W) method. The principle was proposed 30 years ago by Parkin (1956). Noting that many authors of articles on grain damage only reported the percentage of attacked kernels, he urged 'that an attempt should always be made to estimate the corrected weight loss. For example, the percentage of holed beans may be the desirable criterion in an experiment but samples of, say, 100 sound and 100 holed beans, could be weighed, thus allowing conversion to uncorrected weight loss. The 100 damaged beans could then be opened, cleaned of internal insects and dust, and reweighed to give the corrected weight loss, assuming no change in moisture content'.

The loss estimation methodology based on this principle was described by the French Commission for Evaluation of Losses (Anon, 1969). Rather than comparing the mean weight of a mixture of damaged and sound

kernels in samples taken at different times as the TGM method does, the C&W method compares the mean weight of damaged and undamaged kernels from within the same sample.

Using C&W, samples are first cleaned over a sieve to remove insects and other fine material. Some insect frass may also be removed during the cleaning. A small portion is then randomly removed from the cleaned sample. Adams and Schulten (1978) recommended that this portion contain 100-1000 kernels. Each kernel is observed and damaged kernels separated from sound kernels. The kernels in each fraction are then counted and weighed to allow the calculation of the mean kernel weight of each fraction and the proportion of damaged kernels.

<u>Percent damaged X factor method</u>. This method also relies on the difference between the mean weight of damaged kernels and the mean weight of undamaged kernels. To use this method, one simply calculates the percentage of damaged kernels in a grain sample and multiplies this by a factor representing the presumed percent weight lost per damaged kernel. Adams and Schulten (1978) recommended that portions containing from 100-1000 kernels be used to determine the percent damaged, and that portions of 100-1000 kernels, of which at least 10 percent are damaged, be subjected to C&W procedures to determine the conversion factor (called specific loss by Pointel and Coquard, 1979). For preliminary surveys, conversion factors available from the literature may be used (Adams and Schulten, 1978), but DeLima (1978) found the development and frequent revision of 'families' of factors specific to local conditions (e.g.

grain types and varieties, insects present, agronomic and storage conditions) appropriate for detailed loss estimation research.

Bulk density (standard volume weight) method. Bulk density (the mass of a material for each unit of volume it occupies) of grain has been used by much of the grain industry for well over a century as an indicator of processing yield. It remains a factor in standardized methods of quality measurement (including some official U.S. grain grades) for most grains and oilseeds even though it has proved a fairly unreliable predictor of processing yield (Baker and Golumbic, 1970). In wheat, for example, bulk density (also called test weight or volumetric weight) and flour yield are reasonably well correlated through the 52-57 lb/bu (66.9-73.4 kg/hl) range, but poorly correlated in heavier wheat lots (Mangels and Sanderson, 1925; Zeleny, 1978).

The use of changes in bulk density of grain as an indicator of weight loss was proposed by Combs (1963). The methodology for its use in research was described by Adams and Harman (1977) and is known as the standard volume weight (SVW) method.

Because bulk density of grain varies with moisture content, the dry weight per standard volume of sound grain must be determined over a range of moisture contents before this method can be used. Then samples of the same grain are taken after damage is presumed to have occurred. The bulk density (expressed as dry weight) of the damaged sample is compared to the dry bulk density of the sound grain at the same moisture content. The difference is divided by the dry bulk density of the sound grain and the result is multiplied by 100 to calculate the percent reduction. A

one-to-one relationship between loss of bulk density and loss of dry weight is assumed."

Grain Conditioning and Storage

Most of the material reviewed here was taken from Christensen (1969 and 1974), Hall (1970), and Pedersen (1986), unless another author is specified.

Grain moisture content. Moisture is probably the most important factor in grain storage because it has a monetary impact and also because it has a close relationship with factors of grain deterioration (molds, insects, respiration, physical changes in individual kernels and grain masses, and chemical changes and reactions). Moisture is closely interrelated with temperature and when it is present in significant quantity for deterioration to occur, temperature may be the limiting factor. The grain moisture content can be expressed on a wet weight basis (the most common method used in grain trade for grain marketing) or on a dry weight basis (used by engineers and scientists).

Grain cleaning. This is the first mandatory step in the process of grain conditioning because foreign materials in the grain is the source of many handling (plugs in conveyors and bucket elevators), drying (energy waste) and storage (obstacle for aeration, food for insects and molds) problems. The cleaning process can also negatively affect the quality of the grain if the machines are not adjusted correctly for the type of grain being treated.

Grain drying. The major objective of grain drying is to reduce moisture content so spoilage does not occur before use. The advantages of artificial grain drying are:

1. Early or planned harvest because less damage occurs when grain is harvested mechanically at higher moisture contents
2. Long-term storage without deterioration
3. Higher prices after harvest

Since grain is hygroscopic, it tends to hold an appreciable amount of moisture even after drying. For each type of grain there is a definite equilibrium relationship between grain moisture content and relative humidity of the air to which the grain is exposed. According to Christensen (1974), the equilibrium moisture content for a given relative humidity changes slightly with changes in air temperature. The grain and air are in equilibrium when the vapor pressure of the moisture in the grain is equal to that in the air; the net flow of moisture to or from the grain is zero, and its moisture content remains the same.

The factors affecting the rate at which grain will come to moisture equilibrium are temperature (the higher the temperature the faster the rate), moisture content (the higher the moisture content the faster the rate of equilibrium) and the type of grain (nature, size, and shape of kernels). The rate of drying will be faster if the initial moisture content and temperature are high, if the humidity is low, and if the air movement through or past the grain is increased. However, the rate of drying is not proportional in all cases to the amount of moisture remaining to be removed. Another important observation is that evaporation

cools grain during drying so that grain kernels do not reach the air temperature until the equilibrium moisture content is reached. Grain temperature may come very close to that of the air as the decrease in moisture content becomes very slow (low drying rate).

The grain does not need to be dried completely because changes in starch and proteins can take place. All processing methods are for naturally dried grain or equivalent, and their success would be impossible without proper drying. Usually 10 to 14 percent moisture content (wet basis) is the limit for drying because molds may develop at moistures above 14 percent and insect development is considerably reduced below 12 percent moisture content.

The so-called high-temperature drying of grain occurs when the air temperature is so high that severe over-drying would happen if grain stayed in contact with it until the moisture content reached the equilibrium. Therefore, the drying process is continued only until the required moisture content is reached, then the grain is cooled before being transferred to storage. There are three types of high-temperature drying of grain.

Batch drying involves the drying of a static batch of grain, after which it is cooled. The advantages are a high thermal efficiency if grain is several units deep and a relatively small size of the lots of grain. The disadvantages are a non-uniform final moisture content unless the grain is turned, sweating which can occur in the batch, and possible development of molds.

Dryeration occurs when a batch of grain is dried and moved to a tempering bin without cooling, and aeration is used to remove the final 2 percent of moisture content. The advantages are an increase in the dryer capacity and fuel and drying efficiencies, and also a reduction in grain cracking. The disadvantage is the requirement of two bins and transfer equipment.

Continuous flow drying occurs when the grain to be dried flows through the dryer at a controlled rate while heated air is passed through the grain. The flow is commonly controlled by the rate of discharge and the flow may be vertical (by gravity) or horizontal (by belt or fluidized bed). The thermal efficiency depends on the design of the dryer. Some units that function almost like batch or stage dryers have a fairly high thermal efficiency, but some units that pass heated air through rather thin layers of grain show a fairly low thermal efficiency. Continuous flow dryers usually have a cooling section at the bottom or tail end of the dryer. The advantages of this kind of dryer are a more uniform final moisture content, less management required (almost completely automatic), and efficient handling of large grain quantities. The disadvantages are the requirement of fairly large quantities of grain, a high initial investment cost, and no dual use as dryer and storage.

Effects of drying. The temperature reached by the grain itself is important, not the temperature of the drying air. The overheating of the grain during drying can kill the germ, change the nature of the chemical constituents (enzyme systems, protein, oil, starch), crack the endosperm,

"blister" the grain, brown, scorch or char the grain, and ruin the grain for many uses.

"Safe" temperatures for drying depend on the temperature of the grain itself. If short passes are made through the dryer, the air can be much hotter than the "safe" temperature, especially if the grain is not much above 14 percent moisture content when entering the dryer. At 20 percent moisture content and higher, if the temperature is much above that indicated as "safe" the grain may be cooked and thus ruined. The following are recommended "safe" temperatures for corn under different conditions:

1. Seed - $100^{o}F$ ($38^{o}C$) up to $120^{o}F$ ($49^{o}C$) if moisture content is below 25 percent
2. Dry milling - 120^{o} ($49^{o}C$)
3. Wet milling - 130 - $140^{o}F$ (54 to $60^{o}C$)
4. Distilling - $140^{o}F$ ($60^{o}C$)
5. Feeding purposes - up to $280^{o}F$ ($140^{o}C$) with no nutritional loss

For grain sorghum the recommended "safe" temperature is 140 - $150^{o}F$ (60 - $66^{o}C$).

Drying thermal efficiency. The formula used by Chang (1977) was applied in this research. The application of the formula with the required details are shown in Appendix IV.

Temperature and Moisture Changes in Storage (from Hall, 1970)

Spoilage can occur even though precautions have been taken to put only dry grain into storage. Such spoilage results from the existence of

temperature gradients within a stack of bagged grain or a silo of bulk grain. Differences between the temperature of the grain and the outside air temperature (Figure 1) can be communicated to the grain through the walls of the store or silo, particularly if they are constructed of metal. Due to the low thermal conductivity of grain, these temperature effects on the outside of the grain mass are only very slowly transmitted to the center. The temperature of the grain at the center of the bulk may rise due to the presence of insects (Figure 2) and this temperature rise will only be communicated very slowly to the outside of the grain. This shows how a temperature gradient can occur.

These temperature gradients cause convection currents in the grain, accompanied by a movement of moisture from high temperature to low temperature areas. As the air is cooled its relative humidity rises and may reach the saturation point when excess water will be deposited on the surface of the cooler grain (Joffe, 1958). Localized increases of moisture content can therefore occur giving conditions favorable to the development of fungi, resulting in further spoilage of the grain.

If the external air becomes consistently colder than the stored grain and remains so for many weeks, the air within the mass develops a slow but persistent movement pattern, as illustrated by the arrows in Figure 1. The air in the silo adjacent to the outer walls is cooled, its relative humidity rises and as a result there is a slight increase in the local moisture content of the grain. The rise in the relative humidity of the air may bring the air to saturation point when any further increase in moisture content of the air or further reduction in temperature will lead

to liquid water being deposited onto the grain. In due course, the moisture content of the grain at the bottom of the storage container will rise sufficiently for deterioration to occur, as shown by the cross-hatched areas in Figure 1. The dry air rising through the warm central section takes up moisture from the grain. When this warm, moisture-laden air comes into contact with the cool upper surface of the grain, moisture is deposited and another potential area of deterioration develops.

Figure 1 shows an air movement pattern which occurs when the external air temperature is consistently above the grain temperature. High moisture content conditions may develop near the floor if there is no underfloor ventilation. The latter condition is the less common of the two since grain is normally harvested in high temperature conditions and thereafter the temperature of the outside air may be expected to fall.

The lower the moisture content of produce on entry to the store the less the risk that its temperature will fall to below the dewpoint temperature. This is the temperature at which a given sample of air becomes saturated, and below which water starts to condense out. If the temperature of a surface is below the dewpoint of the surrounding air, water will condense onto it.

Condensation problems, especially in metal silos, occur in the tropics particularly in areas where the sky is clear during both day and night. Clear skies result in high daytime temperatures in the wall which, by heating the inside of the store, causes a movement of moisture from the produce to the surrounding air space. At night radiation from the store leads to a very rapid drop in the temperature of the wall and

the water vapor in the air space condenses onto the internal surface of the store. Condensation may not be apparent on cursory inspection since the liquid water may be absorbed by grain in contact with the silo walls. Grain itself can act as a condensing surface if its temperature is reduced to below the dewpoint temperature of the air. The presence of high moisture content grain and areas of mold at the surface of produce indicate that condensation has occurred.

Metal silos should be light in color to reflect most of the incoming radiation during the day. The major temperature changes normally required to cause condensation can be avoided by providing adequate shade to prevent large gains of energy in the grain.

If the grain is uniformly dry when put into the store and is kept dry and at a constant temperature, damage due to condensation and translocation of moisture will be minimal.

The negative processes described below will be accelerated when the grain is stored with poor previous cleaning, nonhomogeneous moisture content, and high temperature. In that case, even by applying fumigation and aeration, the stored grain will probably suffer moisture concentration, heating, insect infestation and mold problems, and the final effect will be a high degree of grain spoilage. How these changes occurred during the storage period is the next subject in this literature review.

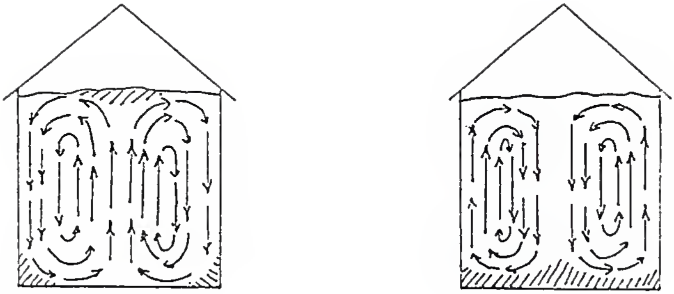


Figure 1. Moisture Movement Within Bulk Of Grain Due To Differences Between The Temperature Of Outside Air And Of Stored Grain. Left, Outside Air Temperature Below Grain Temperature; Right, Outside Air Temperature Above Grain Temperature.

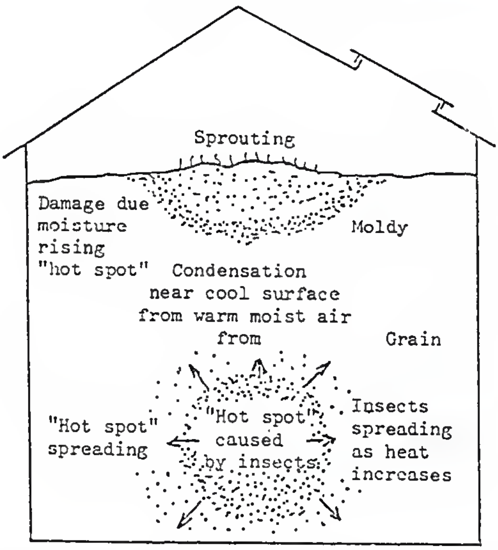


Figure 2. Spoilage Of Grain Due To Temperature Gradients, Movement Of Moisture, And Localized Development Of Fungi And Insects.

Physical and Functional Changes During Storage

Changes take place no matter how grain is stored. Poor storage conditions accelerate changes and good storage conditions retard them but the change can begin before grain is harvested. The primary objective of storage is to maintain quality and minimize deteriorative changes. The physical factors influencing deteriorative changes are:

Moisture Content (the most important). Deterioration is slow at low moisture contents and rapid at high moisture contents. Moisture is closely interrelated with other factors such as temperature, mold, and insect development.

Temperature. Within certain limits, chemical and biological processes proceed at faster rates at higher temperatures and slower at lower temperatures. Lower temperatures slow insect and mold development and high temperatures may destroy enzymes and living organisms.

Oxygen supply. Oxygen is necessary for insects, molds, and certain chemical reactions. So oxygen-free storage is used to preserve dry grain. However, deterioration can occur in the absence of oxygen at high moistures.

Grain condition or "soundness". Damaged kernels (broken, insect, mold) and the presence of foreign materials (weed seeds, stems, other plant materials) increase the potential for deterioration.

An important factor during the storage of grain is respiration. It involves the release of energy through the biochemical oxidation of carbohydrates and other organic nutrients. Respiratory processes occur in every living cell and furnish the energy required to carry on vital

metabolic functions. Total respiration in a grain mass may come from a combination of sources (molds, insects, viable grain kernels). The energy source is the seed which loses dry matter (weight).

Moisture content is the limiting factor in respiration that occurs in a grain mass (grain, microbial, and insect). Rates of respiration at any given moisture tend to remain relatively constant in mold-free grain. Respiration rates of grain invaded by fungi remain relatively constant as long as the moisture content is maintained below that satisfactory for mold growth.

Respiration, whether of seeds, microorganisms, or insects, depends upon chemical reactions and is accelerated by increases in temperature until limited by temperature or some other factor like exhaustion of oxygen or the food source. The respiration of molds and insects is reduced by low temperatures because growth and reproduction are limited.

Heating in grain is a direct result of respiratory activity and occurs when the heat produced as a product of respiration exceeds the grain's ability to dissipate the heat. At low moisture levels (below 13-14 percent) heat produced by respiration of grain is dissipated and the temperature does not increase. At higher levels (above 13-14 percent) or in insect-infested grain, heat produced by respiration of molds and/or insects will cause a temperature increase. There are two stages of heating caused by microorganisms. The first one is attributed to the respiratory activity of molds (ends at about $122^{o}F$-$131^{o}F$ or 50-$55^{o}C$), the second one is due to the thermophilic bacteria (goes up to a maximum of

158°F or 70°C). Continued heating above 158°F is due to chemical oxidation. The respiratory activity of the grain iteself stops at temperatures of 113°F (45°C) and above.

Respiration of insects in a grain mass can be responsible for increases in temperature up to 105-110°F (40-45°C). Temperatures above 110°F (45°C) for any length of time will kill the insects and the tendency is for them to migrate away from the heat source. The heating due to insects can be stopped by controlling the insect population but the heating due to microbial respiration occurring as a result of insect infestation is not prevented by killing the insects.

Indexes of Deterioration of the Stored Grain

1. Increased temperature
2. General appearance
3. Odor
4. Damaged kernels
5. Decreased germination
6. Acidity measurements
7. Glutanic acid decarboxylase activity

Aeration of Grain in Commercial Storages

The United States Department of Agriculture (1985) presented a very good booklet about grain aeration in commercial storages and its summary is included here.

"In the past, grain storage operators periodically 'turned' their stored grain - moved it through the air - to help maintain market quality. Aeration - the moving of air through stored grain - has become a generally accepted practice for maintaining market quality of stored grain without turning it. Aeration is applicable to all types of storages, but it is especially applicable to flat storages where it is difficult to move or turn the grain. In fact, without aeration longtime storage in flat structures is impractical. With aeration, market quality of grain is maintained without moving the grain, and wear and tear on both the grain and handling machinery is reduced. Aeration systems are also effective and efficient in applying fumigants to grain in storage.

An adequate duct system design is as important as a suitable fan. In large flat storages with 'peaked' loading the design of adequate duct systems becomes even more important, and more complicated. It is always advisable to have a good engineering analysis of a proposed duct system and particularly so if the system is to be installed in a peak-loaded flat storage.

The small amount of air used for aeration is not costly to provide. The most commonly used airflow rates range from 1/20 to 1/10 cubic feet of air per minute (cfm) per bushel (0.04 to 0.08 $m^3/min/m^3$). These rates are generally adequate for reducing insect and mold activity and for holding moisture migration and accumulation within acceptable limits. Rates as high as 1/4 cfm per bushel (0.201 $m^3/min/m^3$) are sometimes used in flat or shallow storages where more rapid cooling is desired. Airflow

rates as low as 1/100 cfm per bushel (0.008 $m^3/min/m^3$) were successful in preventing any appreciable moisture migration and accumulation in dry (12.2 percent moisture) shelled corn in the Northern Corn Belt. Recommended airflow rates for each area should be followed for best results.

The installed cost of aeration systems ranges from 1 to 5 cents per bushel capacity (3 to 15 cents per m^3), depending on the size of the storage, the type of system, ease of installation, and other contributing factors. Normal operating (power and labor) costs range from 1/10 to 1/2 cent per bushel per year (0.3 to 1.5 cents per m^3 per year). Power and labor costs for turning grain 4 times a year range from 1/2 to 1 1/2 cents per bushel for the four turns (1.5 to 2.5 cents per m^3).

Aeration usually is accomplished by pulling outside air downward through the grain and exhausting it through the fan. For summer cooling in southern areas, there may be some advantage in forcing the air upward through the grain; the heat trapped under the storage roof then is moved out without passing through the grain. There is little or no difference in power requirements and operating costs for pulling or pushing air through stored grain. Many fan assemblies can be changed on the aeration system to either pull or push air as the operator desires.

The fan horsepower required for aeration varies with the kind of grain, its stored depth, and the airflow rate per bushel. One horsepower (0.736 KW) will aerate up to 20,000 bushels (705 m^3) of shelled corn 100 feet (30 m) deep at 1/20 cfm per bushel (0.04 $m^3/min/m^3$). The same horsepower will aerate only about 5,000 bushels (176 m^3) of wheat 100 feet (30 m) deep at the same airflow rate.

Generally, it is desirable to start cooling summer harvested grain as soon after storing as air temperatures will permit. Aeration to prevent moisture migration should be started early in the fall to keep the temperature of the grain close to the average temperature of the air throughout the fall season. A grain temperature not much below 45° to 50°F (7° to 10°C) generally is suggested if there is a chance that grain will be moved during the hot weather; otherwise, grain temperatures of 35° to 45°F (2° to 7°C) have been satisfactory.

The time required to cool a specific lot of grain by aeration depends on the airflow rate used, methods of operation, uniformity of airflow through the grain, and amount of evaporative cooling and otber similar factors. Grain aerated at an airflow rate of 1/10 cfm per bushel (0.08 $m^3/min/m^3$), and under favorable conditions, can be cooled to near the existing air temperature in about 80 hours in tbe summer, 120 hours in the fall, and 160 hours in the winter. The total elapsed time, in days or weeks required, will depend on the daily hours of operation. Total aeration time per year for a lot of stored grain depends on the number of cooling stages.

It should not be assumed that aeration is an answer to all grain storage problems. Aeration may not completely eliminate all 'turning' of stored grain but it should be considered in future grain storage programs. It can be an important practice in maintaining the market quality of stored grain and in minimizing handling costs.

Use of Aeration

Cooling stored grain to prevent or minimize mold growth and insect activity. Cooling stored grain to prevent mold growth and insect activity includes removal of both natural heat and heat from artificial drying. Aeration for these purposes is widely used in the areas of summer harvest. In the summer, grain often goes into storage at 90°F (32°C) or higher and should be cooled as soon as atmospheric conditions permit. Grain going into storage during the fall months also should be cooled.

There is no one optimum storage temperature for grain. The moisture content of the grain, its probable use (for food, feed, oil, seed), and the length of the storage period (weeks, months, or years) are factors that determine the desirable storage temperature.

Most grain molds grow slowly or not at all below 70°F (21°C). Insect reproduction is stopped, or nearly so, at temperatures below 60°F (15.6°C). Moreover, many insects die from starvation when grain temperatures drop to 40°F (4°C) for any length of time. Most species, excluding moths, are killed in 2.5 months' time at a temperature of 35°F (2°C). (Although aeration is useful in providing lower grain temperatures that help to prevent serious insect infestation and consequent grain loss, it will not entirely replace fumigation and other direct means of insect control.)

Equalizing stored grain temperatures to prevent moisture movement from warm to cooler grain. Temperatures of stored grain are equalized to prevent moisture from moving from warm to cooler grain. This moisture

movement is normal in any storage where appreciable variations in grain temperatures exist, but it is most pronounced in the colder, northern areas of the United States. During the fall and winter months, grain located near exposed walls and upper surfaces cools more rapidly than that in the center of the bin. This temperature difference causes slow convection currents in the bin with the warm air, which rises through the center of the grain mass, carrying moisture from the warmer grain to the colder surface grain. Moisture accumulation may be serious enough to cause molding and crusting on the grain surface and spoilage in other parts of the bin. In stored grain having uniform temperatures, moisture migration does not take place.

Removing odors from stored grain. The 'fresh' grain smell is one of the most striking characteristics of aerated grain. Molding and rancidity of grain causes common storage odors. This condition is minimized by cooler grain temperatures and aeration will either remove or reduce such odors. Some odors can be rapidly dissipated with only a few air changes, while others are more persistent and require longer periods of aeration. Some odors are removed only temporarily or reduced in intensity by aeration. Sour or fermented odors are seldom removed entirely by either aeration or drying. Also, the dissipation of odors from stored grain does not assure freedom from molding and rancidity.

Although little factual information is available in regard to the operational requirement for removing odors, fans usually are operated from 30 minutes to 1 hour, or longer, once every 2 to 4 weeks, or whenever the operator thinks it desirable. With airflow rates recommended

for aeration, from 5 to 20 minutes are required for one complete change of air in the stored grain.

Applying fumigants to stored grain. The introduction of fumigants through an aeration system is a practical method of fumigating grain. The distribution of fumigants is usually more uniform, and the dosage required less, than for gravity methods. The fumigants may be purged from the grain after a prescribed exposure period by operating the fan for a few hours.

With uniform airflow the fumigant can be introduced into the grain in about the time required for one air change. It is desirable to allow from 10 to 20 minutes to meter the fumigant into the airstream, which requires an airflow rate of from 1/20 to 1/10 cfm per bushel (0.04 to 0.08 $m^3/min/m^3$). Higher airflow rates can be used in a closed system where the fumigant can be recirculated through the grain.

Optimum grain temperatures for effective and economical application of fumigants differ according to the method of application. When applied with no aeration to the surface of the stored grain, the grain temperatures should be at least 65°F (18°C). This is necessary for gravity penetration of fumigant to the bottom of the grain bulk in killing concentrations. Grain temperatures are less important when fumigants are applied with aeration. The fumigants can be effectively distributed to all portions of the grain bulk under a fairly wide range of grain temperatures.

Holding moist grain in storage for brief periods. Aeration reduces the hazard of spontaneous heating when it is necessary to hold moist

grain in storage for brief periods. Continuous aeration removes heat generated by mold growth, the principal source of heat, and also helps to slow down mold growth and other deterioration by reducing grain temperatures. However, definite upper limits of moisture and temperature have not been established for moist grain under aeration.

Aeration may be used during periods of heavy receipts of moist grain. By providing safe holding conditions, the load on the drier can be spread out and more grain handled during a given harvest period."

MATERIALS AND METHODS

Facilities

The two types of facilities examined in Costa Rica for this project were purchasing agencies and grain handling and storage plants. The purchasing agencies included one facility in the La China area and two in the Palmar Norte area. Originally the work plan called for two in La China and one in Palmar Norte, but this was changed due to the availability of grain in these two areas. The two grain plants selected were La China and Terraba. Gary Gilbert's grain elevator in Clay Center was also chosen in Kansas for drying tests.

Materials and Equipment

The grain to be used for the studies in Costa Rica was white corn and in Kansas it was milo. The equipment list of required items for the research is given below:

Motomco moisture meter
Convection drying oven
Analytical balance
Digital instruments for temperature and relative humidity
Sling psychrometers
Temperature probe
Thermometers
Airtight sample containers
Plastic sample bags
Metal cans for moisture and other measurements
Sieves
Test weight tester
True density measurement (toluene and graduated-cylinder)
Sample pans and trays
Vacuum sampler
Flashlight
Tape measure
Electrical meter (current, voltage, or watt)
Fuel meters

Manometer
Antidust masks, goggles, and gloves
Gasoline for transportation
Air velocity meter
Two 1,600-MT bins
Grain dryers and cleaners

Experimental Design

The original work plan called for two grain handling methods to be tested in Costa Rica at each of the grain handling plants, one for dry grain and one for wet grain. However, due to the lack of availability of dry grain, only the wet grain methodology was actually used in the studies. The dry grain method is described for illustrative purposes. In both methodologies, five or more samples were to be taken from each operational point.

Method I. The methodology for dry grain receiving and storage operations is described as follows.

1. Record weight of grain received.
2. Obtain grain samples for evaluation of initial condition of grain.
3. Record grain levels inside the bin at the end of grain receiving operation.
4. Obtain grain samples at various locations in a bin after bin is filled.
5. Obtain samples at 30 locations in a grain bin approximately once a month for evaluation of grain condition, and periodically check grain level in the bin during a 4-month storage period.

6. Record ambient air conditions during handling and storage operations (dry-bulb and wet-bulb temperatures, relative humidity, and barometric pressure).
7. Monitor grain temperature, fumigation (type, amount, and date) if applied, and aeration (date, time, fan operation, duration, and static pressures) if applied during storage period.
8. Record the weights of outgoing grain after storage.
9. Obtain samples from outgoing grain lots after storage.
10. Analyze grain samples obtained to determine the following parameters (each parameter will be measured three times):
    a. Moisture content (Motomco and oven methods).
    b. Grain temperature (at the time of sampling).
    c. Test weight.
    d. True density (toluene method).
    e. Percent of broken kernels and impurities percentage (12/64" or 4.8 mm round sieve for corn).
    f. Insect activity by visual inspection (type and approximate population).
    g. Mold activity by visual inspection (type and approximate population).
    h. Aflatoxin activity (approximate level). This will be analyzed for only initial and final samples and three sets of samples obtained monthly during storage period.
11. Calculate the following parameters for grain loss assessment:
    a. Void fraction $= 1 - \dfrac{\text{bulk density}}{\text{true density}}$

b. Packing factor = 1 - void fraction

c. Initial dry matter weight = Initial weight $(1 - m_o)$

d. Final dry matter weight = final weight $(1 - m_f)$

where m_o = Initial moisture content, decimal, wet basis

m_f = Final moisture content, decimal, wet basis

d. Final weight = (initial weight) $\left(\frac{1-m_o}{1-m_f}\right)$

where m_o = Initial moisture content, decimal, dry basis

m_f = Final moisture content, decimal, dry basis

<u>Method II</u>. The methodology for wet grain receiving, cleaning, drying, storage, and unloading operations is described as follows:

1. Record weight of wet corn received.
2. Obtain grain samples for evaluation of initial condition of grain.
3. Obtain grain samples after cleaning operation.
4. Record the total amount of grain cleaned.
5. Record the amount of lifting taken by a cleaner.
6. Obtain electrical energy used during cleaning operation.
7. Conduct drying experiments (in Costa Rica and Clay Center, Kansas)
   a. Two batches (replications) with unclean grain.
   b. Two batches (replications) with clean grain.
   c. Two-hour drying operation/batch.
8. Obtain the following parameters of wet grain just before drying operation:
   a. Initial wet grain weight, if possible.

b. If not, level of grain in a holding bin.

c. Initial moisture content.

d. Test weight.

e. True density.

f. Broken kernels and impurities.

g. Insect/mold damage.

9. Obtain the following parameters during drying operations:

a. Ambient air temperatures and relative humidity

b. Plenum air temperature.

c. Grain temperature.

d. Dryer outlet air temperature.

e. Inlet airflow rate.

f. Static pressure in plenum.

g. Drying time, including shutdowns and any other problems.

h. Electrical power of any moving device involved in drying.

10. Obtain the following parameters of grain samples after drying operations:

a. Final weight of grain, if possible.

b. If not, level of grain in a bin after dried grain is transferred to a bin.

c. Final moisture content.

d. Fuel meter reading (total fuel consumed).

e. Test weight.

f. True density.

g. Broken kernels and impurities.

h. Insect and mold damage, if applicable.

11. Record grain level in bin after bin is filled.
12. Obtain samples after bin filling.
13. Continue from step 5 in Method I.

Purchasing Agencies

The methodology used at the purchasing agencies is described as follows:

1. Record weight of grain received.
2. Obtain the samples for evaluation of initial grain condition.
3. Record the weight of outgoing grain lots.
4. Obtain the samples for evaluation of final grain condition at the purchasing agency.
5. Analyze all grain samples obtained as described in Method I.
6. Record storage practices at the purchasing agency.

Field Experience in Kansas

In order to become familiar with grain storage, handling, and drying operations, Eduardo Arce Diaz accompanied Dr. Do Sup Chung and Dr. Joe Harner to grain storage facilities located in Morganville and Clay Center, Kansas, for a week. First, facilities and grain handling and drying operations were observed and examined. Later, several drying tests were actually conducted on cleaned and uncleaned grain sorghum

using a commercial dryer (a Butler Kan-Sun continuous flow crop dryer, model 10-25-215, grain holding capacity 720 cu^3) at the Clay Center facility. The purpose was to examine energy consumption differences and dryer thermal efficiency variations between the cleaned and uncleaned grain sorghum. The field experience at the above facilities was beneficial to the planned research activities at the CNP facilities in Costa Rica.

Planning of Field Tests in Costa Rica (January to August 1987)

The planning of field tests was one of the most carefully conducted stages in the project, and the researchers at all times were open to suggestions from those people involved in the project. This planning required the active participation of all levels of CNP officials, from top administration officials, executive president, general manager, regional directors, and heads of divisions and departments down to plant managers and their workers.

With the special support of the Quality Control Department of CNP, meetings were held with the people in charge of the management of the regions involved in the project, in order to define dates and resources needed to start the data collection. At the same time, aspects of the technical approach of the methodology were carefully set forth. The data collection periods, including monthly samplings, were tentatively scheduled and many other activities were planned.

Data Collection in Costa Rica

The initial data collection period at Planta La China ran from February 16-26, 1987. For Planta Terraba, the dates were March 5-12, 1987. The objective was to record the initial condition of the grain that would be studied for a 4-month period inside a 1,600-MT bin which was exclusively devoted to the research (one bin at each plant). The parameters measured were previously described in this section.

After this initial step, several short data collection periods were developed on a monthly basis to get information on the condition of the grain inside the bins, until the grain was finally unloaded at the end of the 4-month storage period. The final condition of the grain was carefully recorded.

For sample analysis work, the temperature of tbe samples was measured on site. The moisture content, impurities, broken kernels, damage by insects and molds, and densities were measured at the laboratory of each elevator. The more complicated tests like the aflatoxin test and the oven moisture content test were performed at CNP's Quality Control Laboratory. The CIGRAS laboratory did the aflatoxin tests on the samples that came from the receiving hoppers and the bin filling points of both La China and Terraba Plants. In tbe case of La Cbina, all the analysis was done at CNP's Quality Control Laboratory since it is in the same location as the elevator.

The analysis work was always performed immediately after the samples were taken. In the case of Terraba, those samples sent by bus to the Quality Control Laboratory in Heredia were analyzed after 3 days, but

precautions were always taken to preserve the original condition of the sample. The samples analyzed at the CIGRAS laboratory were refrigerated and analyzed over a longer period of time (2 to 3 months).

The flow diagrams of both the La China and Terraba Plants (with the sampling points marked on the diagrams) are shown in Appendix I.

Nomenclature. The following nomenclature was used to define the 30 sampling points inside each storage bin, and also to conduct the statistical analysis of the in-bin variations of temperatures, Motomco moisture content, and damage by insects. The definition of the 30 sampling points inside the bins was made by levels of depth (three levels represented by the vertical distance between each level and the grain surface). Ten sampling points were defined in each level, one in the geometric center and the other nine distributed on three radial lines (120° apart) in groups of three points (2.1 m apart) on each radius. The radial lines were identified by the orientation they had (west-east-north-south or their combinations). The horizontal distances from the center of the bin on each radius represented each of the three sampling points on the radial lines. This way every sampling point was specified by three items (except the central points): a letter of the alphabet to indicate the orientation (radius), a number to indicate the depth in meters (level), and a number to indicate the horizontal distance in meters on the radius (distance). The following are the letters and numbers used.

C = central point	2 = 2.1 m		The numbers 2 through 7 were used in the specification of the samples to represent the corresponding values in meters (right hand side of the equal symbol) for the depths and distances inside the bin.
W = west radius	4 = 4.2 m		
E = east radius			
NW = northwest radius	5 = 4.6 m		
SW = southwest radius			
SE = southeast radius	6 = 6.3 m		
NE = northeast radius	7 = 7.0 m		

For the statistical analysis the following symbols were used.

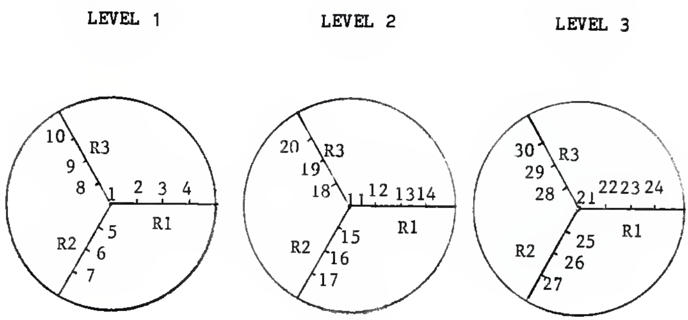
ENV = environment, 1: La China Plant, 2: Terraba Plant

LEVEL = depth in the bin, 1 = 2.1 meters
2 = 4.6 meters
3 = 7.0 meters

DIST = distance from center of bin, 0 = center point
1 = 2.1 meters
2 = 4.2 meters
3 = 6.3 meters

	La China	Terraba
1:	West	East
RAD = radius, 2:	Southeast	Southwest
3:	Northeast	Northwest

LOC = location



LOCATIONS LA CHINA	
1 = C-2	16 = SE-4-5
2 = W-2-2	17 = SE-6-5
3 = W-4-2	18 = NE-2-5
4 = W-6-2	19 = NE-4-5
5 = SE-2-2	20 = NE-6-5
6 = SE-4-2	21 = C-7
7 = SE-6-2	22 = W-2-7
8 = NE-2-2	23 = W-4-7
9 = NE-4-2	24 = W-6-7
10 = NE-6-2	25 = SE-2-7
11 = C-5	26 = SE-2-7
12 = W-2-5	27 = SE-2-7
13 = W-4-5	28 = NE-2-7
14 = W-6-5	29 = NE-4-7
15 = SE-2-5	30 = NE-6-7

LOCATIONS TERRABA	
1 = C-2	16 = SW-4-5
2 = E-2-2	17 = SW-6-5
3 = E-4-2	18 = NW-2-5
4 = E-6-2	19 = NW-4-5
5 = SW-2-2	20 = NW-6-5
6 = SW-4-2	21 = C-7
7 = SW-6-2	22 = E-2-7
8 = NW-2-2	23 = E-4-7
9 = NW-4-2	24 = E-6-7
10 = NW-6-2	25 = SW-2-7
11 = C-5	26 = SW-4-7
12 = E-2-5	27 = SW-6-7
13 = E-4-5	28 = NW-2-7
14 = E-6-5	29 = NW-4-7
15 = SW-2-5	30 = NW-6-7

RESULTS AND DISCUSSION

Results of Grain Loss Assessment in CNP

The results presented here correspond to the data collected at the two CNP plants and some of the surrounding purchasing agencies. The elevators chosen were Planta La China in San Joaquín de Flores, Heredia, and Planta Terraba, Palmar Norte, Puntarenas. The purchasing agency in San Isidro de El General was used for the study of grain going to La China, and the purchasing agencies of El Roble and Rio Bonito were used for the study of grain going to Planta Terraba.

In studies of grain found at the purchasing agencies and the variation of the grain quality during the in-plant conditioning and storage processes, the emphasis was focused on the initial, middle, and final condition of the grain. The following parameters were measured at different stages: weight, moisture content (Motomco and oven), temperature, bulk and true densities, percent of broken kernels, percent of impurities, percent of grain damaged by molds and insects, and aflatoxin levels. Tables 1 and 2 show this information for the grain lots analyzed at the purchasing agencies at the time of arrival and departure from the agency, and the time of arrival at the corresponding elevator. Tables 1-AII through 20-AII in Appendix II show the data collected at the different steps of the grain conditioning and storage processes for each parameter at both elevators. Samples were taken and analyzed from the time the grain was received at the hopper until the time the grain was unloaded from the storage bin. Data on the monthly variations of the

grain condition during the storage period were also included in Appendix III (Tables 1-AIII through 24-AIII).

Purchasing Agencies. Table 1 describes data on the three lots from the purchasing agency of San Isidro de El General in the La China Plant area. The first value on the left for each parameter corresponds to lot A, the second value corresponds to lot B, and the third value corresponds to lot C. The three lots left the purchasing agency shortly after they arrived and got to the La China Plant the next day. The data on the arrival weight at Planta La China could only be obtained for lot C due to the difficulties involved in the normal operation of the plant.

Table 2 describes data on the two lots from the purchasing agencies of El Roble (lot A) and Rio Bonito (lot B) in the Terraba Plant area. The first value on the left for each parameter corresponds to lot A (from El Roble Agency) and the second value corresponds to lot B (from Rio Bonito Agency). Lot A stayed at the agency for 3 days and arrived at the plant on the fourth day. Lot B stayed at the agency for 1 day and arrived at the plant the same day.

La China Plant. Tables 1-AII through 10-AII in Appendix II illustrate the data collected at different sampling points of the grain conditioning and storage processes at the La China Plant. The first four columns were generated with the data taken during the grain receiving period (2 weeks). The following five columns show the information about the grain condition during the storage period in the bin, and the last two columns correspond to the data acquired during the unloading process of the grain from the bin.

The following parameters were noted at the La China plant:

Internal bin diameter: 14.575 m (47.8') Internal bin height: 14.175 m (46.5')

Initial total grain weight	889,646.5 kg (1,961, 301 lb)
Weight of lifting	3,481.5 kg (7,675 lb)
Initial grain weight without lifting	886,165.0 kg (1,953, 626 lb)
Initial grain level inside the bin	6.605 m (21.7 feet)
Final grain weight after unloading	854,393.5 kg (1,883, 583 lb)
Final grain level inside the bin	6.55 m (21.5 feet)

Terraba Plant. Tables 11-AII through 20-AII in Appendix II detail the data collected at different sampling points of the grain conditioning and storage processes at the Terraba Plant. The first four columns were generated with the data taken during the grain receiving period. The following five columns show the information about the grain condition during the storage period in the bin, and the last two columns correspond to the data acquired during the unloading process of the grain from the bin.

The following parameters were noted at the Terraba plant:

Internal bin diameter: 14.55 m (47.7') Internal bin height: 14.215 m (46.6')

Initial total grain weight	956,466 kg (2,108, 611 lb)
Weight of lifting	3,409 kg (7,515 lb)
Initial grain weight without lifting	953,057 kg (2,101, 096 lb)
Initial grain level inside the bin	7.45 m (24.4 feet)

TABLE 1. RESULTS ON QUALITY OF THE THREE LOTS OF GRAIN ANALYZED AT THE PURCHASING AGENCY AROUND LA CHINA PLANT

GRAIN PARAMETER	ARRIVAL AT PURCHASING AGENCY		ARRIVAL AT THE PLANT	
	VALUE	AVERAGE	VALUE	AVERAGE
Temperature, °C	26.6-26.6-26.6	26.6	27.2-25.5-25.9	26.2
Motomco Moisture Content, %	14.93-13.99-14.21	14.37	13.92-13.92-14.64	14.16
Bulk Density, Kg/HL	75.3 -74.93-75.28	75.17	76 -75.9 -73.76	75.22
True Density, Gr/cm^3	1.28- 1.30- 1.28	1.28	1.33- 1.26- 1.29	1.29
Impurities, %	0.46- 0.96- 0.8	0.74	1.0 - 0.86- 1.62	1.16
Brokens, %	1.7 - 3.6 - 3.18	2.82	1.76- 4.56- 3.93	3.41
Damage by Insect, %	0.5 - 0.44- 0.16	0.36	0.16- 0.03- 0	0.06
Damage by Molds, %	0.58- 0.12- 0.11	0.27	0.40- 0.03- 0	0.14
Aflatoxins, PPB	12-130-13	52	-----	----
Weight of Lot, Kg	8023-8112-7881	8005	7850	----

TABLE 2. RESULTS ON QUALITY OF THE TWO LOTS OF GRAIN ANALYZED AT THE PURCHASING AGENCIES AROUND TERRABA PLANT

GRAIN PARAMETER	ARRIVAL AT PURCHASING AGENCY		DEPARTURE FROM AGENCY		ARRIVAL AT PLANT	
	VALUE	AVERAGE	VALUE	AVERAGE	VALUE	AVERAGE
Temperature, ^{o}C	26- 27.8	26.9	26.6- 23.3	25	25.5-27.9	26.6
Motomco Moisture Content, %	17.39-15	16.19	16.84-15.22	16.03	15.52-15.5	15.51
Bulk Density, Kg/HL	76.26-78.66	77.46	76.7 -78.8	77.75	76.56-79	77.78
True Density, Gr/cm^3	1.27- 1.32	1.29	1.32- 1.35	1.33	1.34- 1.30	1.32
Impurities, %	0.56- 0.36	0.46	0.60- 0.33	0.46	1.06- 0.36	0.71
Brokens, %	0.80- 1.33	1.06	0.53- 1.33	0.93	0.36-	0.36
Damage by Insect, %	0.13- 0	0.06	0 - 0	0	0.8 - 0	0.4
Damage by Molds, %	0.90- 0.43	0.66	0.56- 0.5	0.53	0.1 - 0.16	0.13
Aflatoxins, PPB	15-15	15	25-100	62	---	--
Weight of Lot, Kg	12791-4530	8660.5	12821-4460	8640	12791-4370	8560

Final grain weight after unloading	917,823 kg	(2,023, 419 lb)
Final grain level inside the bin	7.465 m	(24.5 feet)

Discussion of Grain Loss Assessment in CNP

The following discussion is strictly limited to the ranges of data collected within tbe specific space-time conditions of the research. Due to the statistical nature of the analysis, extrapolations are not recommended. The statistical and otber quantitative analyses of the results were performed and their results are presented.

Purchasing Agencies. The amount of data collected from the three lots in the La China area and the two lots in the Terraba area was not sufficient to conduct a statistically significant analysis. However, the experience confirmed that by following the lots of grain from purchasing agencies, valuable information can be generated with which to judge handling practices. For future research opportunities, careful planning of this aspect should be done because the collection of data is particularly difficult if a large number of grain lots are followed.

The general impression derived from the observations made on the purchasing agency operations indicates that such agencies are susceptible places for mold and insect development during the time the grain lots remain there. The reason is simple. Very poor storage conditions characterize most of the agencies. Very old buildings with roofs and walls in poor condition and a clearly insufficient storage area make it necessary sometimes to store grain directly on the floor and/or outside in the agency surroundings. There is also a lack of order and cleanliness in most of the purchasing agencies.

La China and Terraba Plants. Table 3 shows the average values calculated from the data collected at each stage of the different processes that the grain underwent at the elevators. The standard deviation value is also included. Tables I-AIII through 24-AIII in Appendix III on the grain temperature, moisture content, and damage by insect variations represent the general data by location and date, and the average variations by level, by radius, by distance, and the whole bin total variations. Figures 3 to 20 show the graphs of the average variations mentioned above.

Table 4 presents a summary of the grain conditions before and after the storage period for both elevators, La China and Terraba.

Table 5 is a summary table of the statistical analysis performed on the data regarding the grain conditioning and unloading processes. The words YES and NO represent the existence (YES) or nonexistence (NO) of statistically significant differences between the initial and final levels of a certain parameter measured during the experiment. A (+) means that the initial value was greater than the final one, and a (-) means that the initial value was smaller tban tbe final one.

Table 6 shows the different figures used to calculate the dry matter loss at each elevator from the data presented in the results section.

La China Plant. A dry matter loss of 1.68 percent is an acceptable figure for weight loss, but the causes of this loss can be understood from the analysis of the qualitative changes undergone by tbe grain inside the bin. Table 5 shows that the damage caused to the grain by insects was significantly bigher at the end of the storage period tban it

TABLE 3. AVERAGES AND STANDARD DEVIATIONS OF THE PARAMETERS MEASURED AT THE ELEVATORS LA CHINA AND TERRABA DURING THE CONDITIONING, STORAGE, AND UNLOADING PROCESSES

LA CHINA

	HOPPER		AFTER CLEANING		AFTER DRYING		BIN FILLING POINT		AFTER FILLING[1]	
	AV.	S.D	AV.	S.D	AV.	S.D	AV.	S.D	AV.	S.D
Temperature, °C	25.1	2.2	26.2	1.1	46.6	8.5	41.0	5.4	27.3	3.2
Oven Moist. Cont., %	13.74	0.99	--	--	--	--	13.08	0.33	12.45	0.08
Mot. Moist. Cont., %	14.18	1.21	14.48	0.97	12.98	0.73	13.25	0.76	12.38	0.30
Bulk Density, Kg/HL	75.04	1.70	75.93	1.10	75.58	0.65	75.79	0.59	76.02	0.65
True Density, gr/cm^3	1.27	0.02	--	--	--	--	1.30	0.02	1.3	0.02
Impurities, %	0.67	0.32	0.61	0.24	0.52	0.19	0.43	0.09	1.26	1.21
Brokens, %	1.24	1.06	1.54	0.77	1.11	0.50	1.44	0.81	2.24	0.76
Damage by Insects, %	0.15	0.14	0.07	0.1	0.18	0.14	0.12	0.10	0.23	0.14
Damage by Molds, %	0.46	0.63	0.55	0.61	0.49	0.39	0.29	0.25	0.31	0.26
Aflatoxins, PPB	78	155	--	--	--	--	105	96	78	73

[1]These measurements were taken several days after the bin was completely filled and after the grain inside the bin had been aerated.

TABLE 3. (Continued)

LA CHINA

GRAIN PARAMETER	FIRST STORAGE MONTH		SECOND STORAGE MONTH		THIRD STORAGE MONTH		FOURTH STORAGE MONTH		UN-LOADING POINT		TRUCK LOADING	
	AV.	S.D	AV.	S.D	AV.	S.D	AV.	S.D	AV.	S.D	AV.	S.D
Temperature, ^{o}C	32.3	1.4	29.2	1.8	21.4	2.2	26.2	0.6	25.5	0.6	26.5	2.1
Oven Moist. Cont., %	12.50	0.11	12.26	0.13	12.22	0.06	12.26	0.32	12.18	0.43	12.24	0.26
Mot. Moist. Cont., %	12.21	0.32	12.77	0.32	12.85	0.35	13.03	0.63	12.34	0.29	12.53	0.29
Bulk Density, Kg/HL	75.96	0.78	76.01	0.77	76.03	0.80	75.6	0.76	74.24	0.34	74.49	0.46
True Density, gr/cm^3	1.31	0.03	1.26	0.01	1.28	0.01	1.27	0.01	1.29	0.03	1.29	0.02
Impurities, %	1.59	1.33	1.48	1.27	1.35	1.61	0.86	1.03	1.46	0.65	0.88	0.88
Brokens, %	2.53	0.96	1.76	0.54	1.61	0.59	1.70	0.97	1.34	0.79	1.50	0.47
Damage by Insects, %	0.19	0.19	0.41	0.45	0.41	0.24	0.40	0.25	0.69	0.28	0.74	0.43
Damage by Molds, %	0.50	0.48	0.47	0.51	0.83	0.57	1.11	3.72	0.14	0.09	0.06	0.05
Aflatoxins, PPB	83	84	82	39	45	17	78	43	91	118	--	--

TABLE 3. (Continued)

TERRABA

	HOPPER		AFTER CLEANING		AFTER DRYING		BIN FILLING POINT		AFTER FILLING[1]	
	AV.	S.D	AV.	S.D	AV.	S.D	AV.	S.D	AV.	S.D
Temperature, ^{o}C	29.4	1.5	29.6	0.8	56.2	3.1	54.7	3.7	32.0	1.0
Oven Moist. Cont., %	14.32	1.74	--	--	--	--	12.31	0.49	11.46	0.27
Mot. Moist. Cont., %	15.67	1.46	15.74	1.02	13.29	0.65	13.24	0.80	11.25	0.48
Bulk Density, Kg/HL	75.60	0.83	76.64	0.79	76.11	1.29	75.2	1.2	76.92	0.46
True Density, gr/cm^3	1.29	0.02	1.29	0.02	1.31	0.03	1.30	0.03	1.28	0.04
Impurities, %	0.77	0.42	0.43	0.09	0.57	0.23	1.07	0.74	1.72	1.34
Brokens, %	1.77	1.66	1.47	0.83	1.78	0.65	2.06	0.83	1.61	0.55
Damage by Insects, %	0.16	0.18	0.25	0.30	0.23	0.37	0.09	0.09	0.09	0.11
Damage by Molds, %	0.82	1.11	0.63	0.32	0.58	0.52	0.62	0.42	0.57	0.26
Aflatoxins, PPB	69	93	--	--	--	--	73	71	33	15

[1]These measurements were taken several days after the bin was completely filled and after the grain inside the bin had been aerated.

TABLE 3. (Continued)

TERRABA

GRAIN PARAMETER	FIRST STORAGE MONTH		SECOND STORAGE MONTH		THIRD STORAGE MONTH		FOURTH STORAGE MONTH		UN-LOADING POINT		TRUCK LOADING	
	AV.	S.D	AV.	S.D	AV.	S.D	AV.	S.D	AV.	S.D	AV.	S.D
Temperature, °C	30.4	1.0	27.7	1.5	33.7	1.4	34.9	1.2	34.5	1.0	34.4	0.8
Oven Moist. Cont., %	11.36	0.35	11.41	0.28	11.62	0.39	11.63	0.26	11.38	0.25	11.46	0.19
Mot. Moist. Cont., %	11.25	0.38	11.41	0.49	11.94	0.49	11.35	0.43	11.76	0.25	11.80	0.42
Bulk Density, Kg/HL	76.72	0.61	76.67	0.47	76.63	0.46	76.02	0.40	75.45	0.24	75.79	0.87
True Density, gr/cm^3	1.29	0.02	1.30	0.01	1.28	0.03	1.30	0.01	1.29	0.001	1.29	0.01
Impurities, %	0.96	0.64	1.07	0.83	1.09	0.64	1.85	1.49	0.63	0.24	0.59	0.37
Brokens, %	1.77	0.64	2.16	0.61	1.66	0.60	1.75	0.97	1.72	0.36	3.08	1.23
Damage by Insects, %	0.22	0.24	0.23	0.17	0.29	0.28	0.37	0.18	0.10	0.09	0.22	0.16
Damage by Molds, %	0.42	0.37	0.09	0.08	0.52	0.33	0.05	0.09	0.03	0.06	0.02	0.03
Aflatoxins, PPB	37	6	58	49	50	30	42	10	31	9	--	--

TABLE 4. SUMMARY OF THE GRAIN CONDITIONS BEFORE (IN) AND AFTER (OUT) THE STORAGE PERIOD FOR ELEVATORS LA CHINA AND TERRABA

PARAMETERS	IN (BIN FILLING POINT)				OUT (BIN FILLING POINT)			
	LA CHINA		TERRABA		LA CHINA		TERRABA	
	AVER.	S.D	AVER.	S.D	AVER.	S.D	AVER.	S.D
Temperature, ^{o}C	41.0	5.4	54.7	3.7	25.5	0.6	34.5	1.0
Oven Moisture Content, %	13.08	0.33	12.31	0.49	12.18	0.43	11.38	0.25
Motomco Moisture Content, %	13.25	0.76	13.24	0.80	12.34	0.29	11.76	0.25
Bulk Density, Kg/Hl	75.79	0.59	75.2	1.2	74.24	0.34	75.45	0.24
True Density, gr/cm^3	1.30	0.02	1.30	0.03	1.29	0.03	1.29	0.001
Impurities, %	0.43	0.09	1.07	0.74	1.46	0.65	0.63	0.24
Brokens, %	1.44	0.81	2.06	0.83	1.34	0.79	1.72	0.36
Damage by Insect, %	0.12	0.10	0.09	0.09	0.69	0.28	0.10	0.09
Damage by Molds, %	0.29	0.25	0.62	0.42	0.14	0.09	0.03	0.06
Aflatoxins, PPB	105	96	73	71	91	118	31	9

TABLE 5. ANALYSIS OF RESULTS ON QUALITATIVE GRAIN LOSSES AT LA CHINA AND TERRABA PLANTS

STATISTICALLY SIGNIFICANT DIFFERENCES ON THE INITIAL AND FINAL LEVEL OF	LA CHINA	TERRABA
Aflatoxins at Storage	NO	NO
Initial aflatoxins level	76	69
Broken Grains	NO	NO
Oven Moisture Content During Storage	YES (+)	NO
Motomco Moisture Content During Storage	NO	NO
Damage by Insects During Storage	YES (-)	NO
Bulk Density During Storage	YES (+)	NO
Impurities During		
Cleaning process - first cleaning machine	YES (+)	YES (+)
Cleaning process - second cleaning machine	YES (+)	--
Storage period	YES (-)	YES (+)
Grain Temperature	YES (+)	YES (+)
Damage by Molds	NO	NO

TABLE 6. ANALYSIS OF RESULTS ON QUANTITATIVE GRAIN LOSSES AT LA CHINA AND TERRABA PLANTS

ITEM	LA CHINA	TERRABA
	VALUE	VALUE
Initial Weight (including lifting)	889,646.5 Kg	956,466 Kg
Weight of Lifting	3,481.5 Kg	3,409 Kg
Initial Weight without Lifting	886,165.0 Kg	953,057 Kg
Weight of Samples Pulled Out From Hopper and Cleaning Machine	841.21 Kg	507.14 Kg
Initial Average Oven Moisture Content (at hopper)	13.74%	14.32%
Weight of Initial Dry Matter	764,405.9 Kg	816,579.2 Kg
Weight of Dry Matter of Samples From Hopper and Cleaning Machine	725.62 Kg	434.51 Kg
Final Weight of Grain	854,393.5 Kg	917,823 Kg
Weight of Samples Pulled Out During Conditioning, Storage, and Unloading Processes	1,159 Kg	948 Kg
Final Average Oven Moisture Content (truck loading point)	12.24%	11.46%
Weight of Final Dry Matter	749,815.7 Kg	812,640.5 Kg
Weight of the Dry Matter of Storage Samples	1,017 Kg	839 Kg
Weight of Final Dry Matter Plus the Samples of Dry Matter	751,558 Kg	813,914 Kg
Difference Between Initial and Final Dry Matter	12,848 Kg	2,665 Kg
PERCENTAGE OF DRY MATTER LOSS	1.68%	0.32%

was at the beginning (this is the meaning of the expression YES (-) in the table). The effect of insect activity inside the bin at La China was also confirmed by the significant decrease of the grain bulk density (YES (+)) during the storage period. The average percentage of grain damaged by insects at the initial storage condition was 0.12 percent and the percentage at the final storage condition was 0.69 percent. The average bulk density value decreased from 75.79 kg/hl or 58.93 lb/bu (at the initial storage condition) to 74.24 kg/hl or 57.73 lb/bu (at the final storage condition). The average percentage of impurities increased from 0.43 percent to 1.45 percent during the storage period.

The level of aflatoxin in parts per billion (ppb) did not increase significantly between the time the grain arrived at the hopper and the time it was unloaded from the bin at the end of the storage period. The initial average level was 76 ppb and the final average level was 91 ppb. However, these are high and completely unacceptable aflatoxin levels according to health standards (20 ppb is the maximum for human consumption in the United States).

The first cleaning machine removed significant amounts of impurities because the average weight of grain lifting recorded daily was 0.28 percent of the weight of grain received at the hopper.

Some drying and cooling of the grain took place during the storage period. The average oven moisture content decreased from 13.08 percent to 12.18 percent and the average grain temperature decreased from 106^{o}F (41^{o}C) to 78^{o}F (26^{o}C). A total of 101 hours of aeration was applied to the grain during the storage period.

There were no significant differences between the initial and final levels of the average percentage of broken kernels and the average damage by molds.

From Figures 3-11 and also Tables 1-AIII through 12-AIII in Appendix III, it is possible to describe how the changes in temperature, moisture content and damage by insects occurred inside the bin during the storage period in the La China plant.

Temperature. The differentials between grain temperature and atmospheric temperature were greater than 10^{o}F (5.5^{o}C) in all the figures for February (10^{o}F or 5.5^{o}C), March (15^{o}F or 8.3^{o}C), and April (11^{o}F or 6.2^{o}C), with the smallest differential in May (2^{o}F or 1.1^{o}C) below the atmospheric temperature) and the largest one in March (15^{o}F or 8.3^{o}C).

Differentials between levels, between radii in a level, and between distances in a level were usually not greater than 10^{o}F (5.5^{o}C) for any month (for the average values Figures 3, 4, and 5).

The average temperature of level 1 (nearest level to the bin's roof) tended to be higher than those of the other two levels - especially during the months of February, March, and April - but the differential never reached a value greater than 10^{o}F or 5.5^{o}C (Figure 3).

Except for level 3, in all the levels the average temperatures for radius one (radius in line with the western side of the bin's wall exposed to sunshine) were higher than those of the other radii especially for the months of March, April, and May - but the differential never reached a value greater than 10^{o}F or 5.5^{o}C (Table 3-AIII).

In all the levels, the average temperatures for distance 1 (the closest distance to the bin's central point - 2.1 meters apart) were higher than those of the other two distances - especially for the months of February, March, April, and May - but that differential never reached a value greater than $10^{o}F$ or $5.5^{o}C$ (Table 4-AIII and Figure 5).

In general, the grain temperature followed the increasing-decreasing trend of the atmospheric temperature for the first 3 months of storage. Then in May, grain temperature was lower than ambient temperature, and in June, grain temperature increased again, while atmospheric temperature continued decreasing (Figure 6).

Motomco Moisture Content. The whole bin average differentials had a maximum of 0.8% of moisture content (wet basis). The lowest value was recorded in March (12.2%), and the highest one in June (13%) (Figure 10).

The grain moisture content followed the tendency of the increasing relative humidity during the storage period, except for the time from February to March, in which the moisture content decreased from 12.4% to 12.2% (Figure 10).

Average values by levels followed the increasing tendency of the relative humidity. The differentials between levels reached the maximum value in June, between level 1 and level 3 (0.7% of moisture content), and the minimum value in February, between either level 1 or 3 and level 2 (0.1% of moisture content) (Figure 7).

For every month of storage, the average moisture content of level 1 tended to be the highest among the three levels (except in May, when level 2 had the highest value). Level 2 tended to have the second highest value for all the storage months except in May (Figure 7).

The average values by radius over the three different levels showed the following variations (Table 8-AIII).

Level 1 showed the maximum differential in February, between radius 2 and radius 3 (0.9% of moisture content). Tbe radius with the highest values was 2.

Level 2 showed tbe maximum differential in June, between radius 1 and radius 3 (0.8% of moisture content). The radius with tbe higbest values was 3, except for February and June, when radius 2 had the highest values.

Level 3 showed the maximum differential in June, between radius 1 and radius 3 (1.1% of moisture content). The radius with the highest values was 3, except for February when 2 had the highest values.

For the three levels, radius 3 had an increasing, almost linear tendency.

For level 2 and 3, radius 1 had a decreasing tendency in March and June.

Radius 2 followed the general behavior of the whole bin variation.

The average values by distance over the three different levels showed the following variations (Table 9-AIII).

Level 1 showed the maximum differential in March, between distance 1 and 3, in May, between distance 1 and 2, and in June, between distance 1 and 2. In all the cases, tbe value was 0.5% of moisture content. Distance 2 had the highest values in April, May, and June.

Level 2 showed the maximum differential in March, May, and June, exactly as in level 1. Distance 3 had tbe highest values in March, April, and May, and distance 2 had them in February and March.

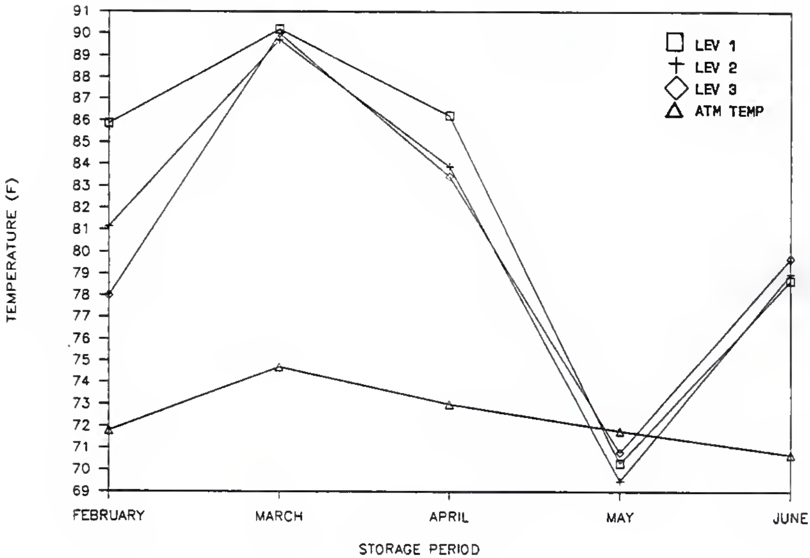


Figure 3. Grain Temperature (Monthly Averages) at Different Levels Inside the Bin During Storage at "La China" Facility

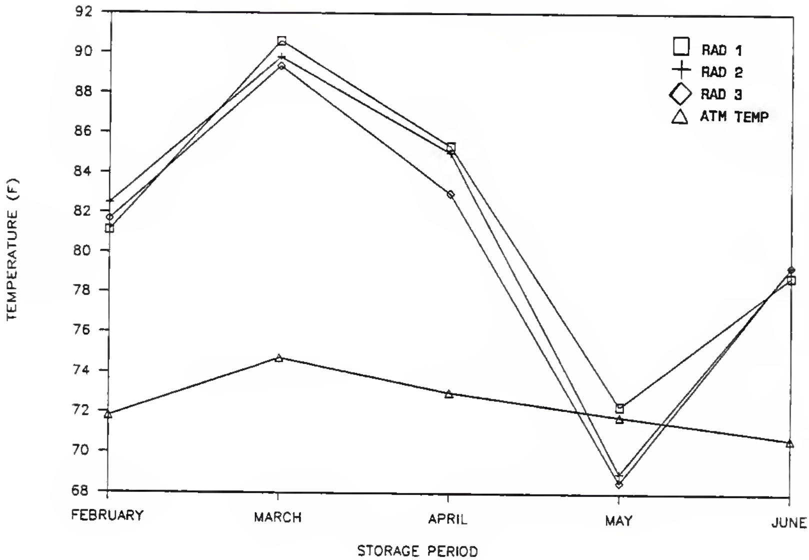


Figure 4. Grain Temperature (Monthly Averages) at Different Radii Inside the Bin During Storage at "La China" Facility

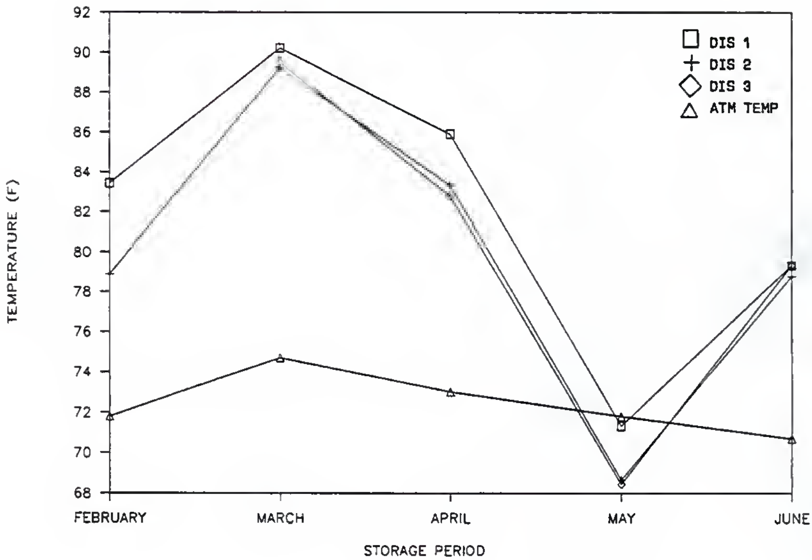


Figure 5. Grain Temperature (Monthly Averages) at Different Distances Inside the Bin During Storage at "La China" Facility

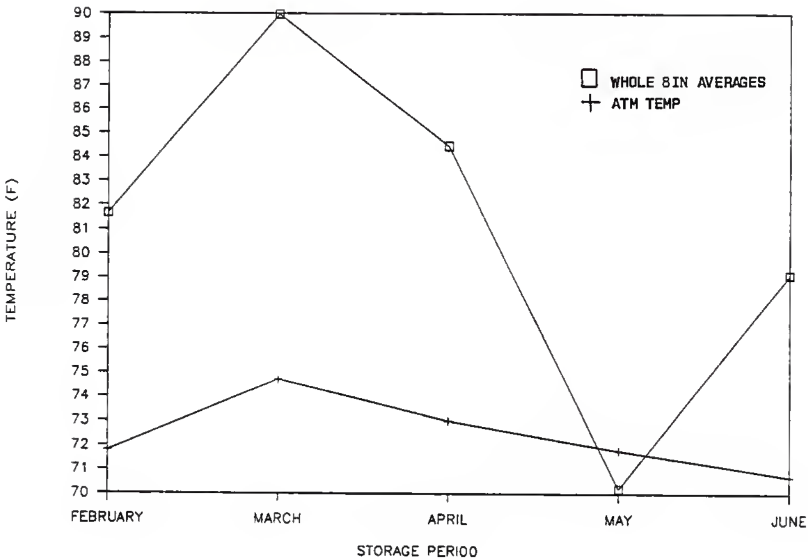


Figure 6. Grain Temperature (Monthly Averages) of the Whole Bin During Storage at "La China" Facility

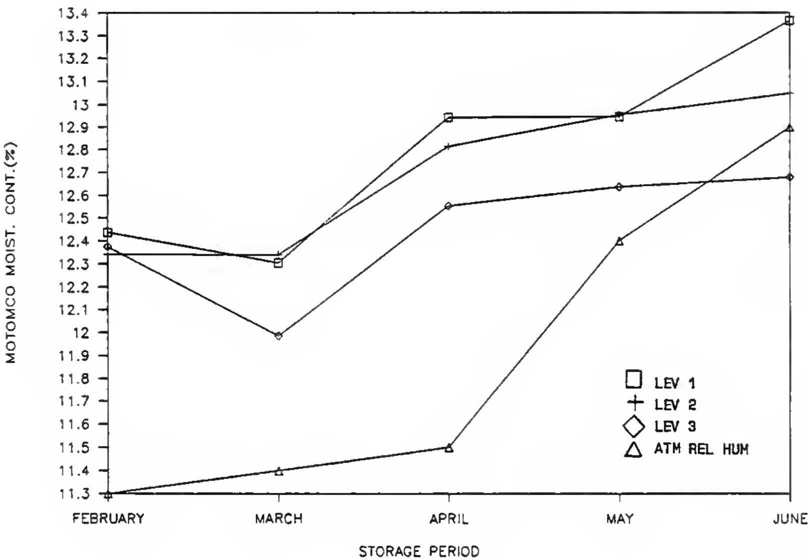


Figure 7. Grain Motomco Moisture Content (Monthly Averages) at Different Levels Inside the Bin During Storage at "La China" Facility

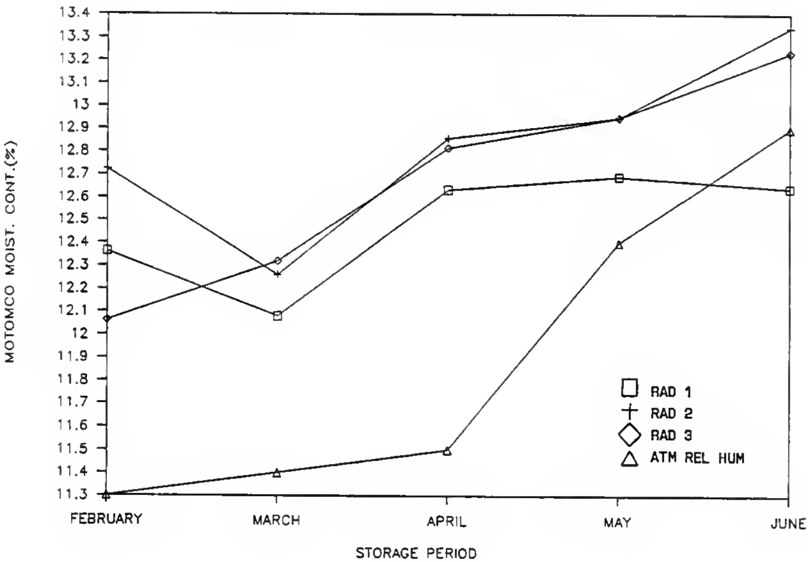


Figure 8. Grain Motomco Moisture Content (Monthly Averages) at Different Radii Inside the Bin During Storage at "La China" Facility

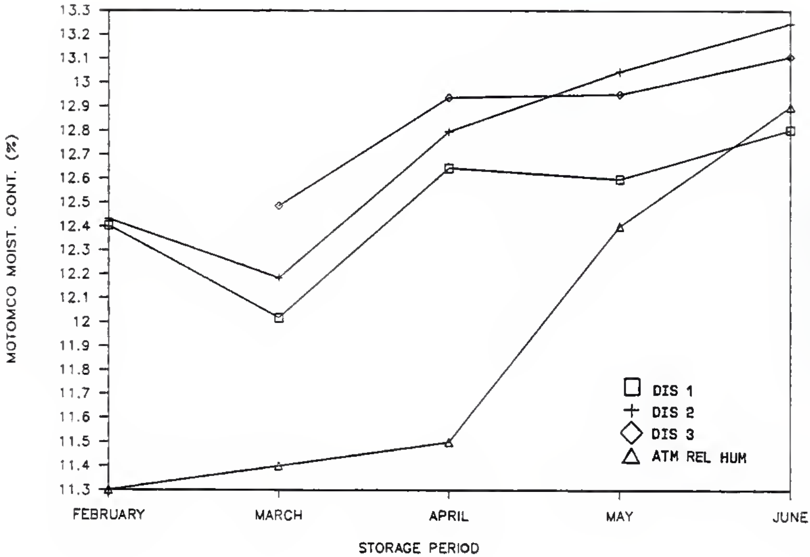


Figure 9. Grain Motomco Moisture Content (Monthly Averages) at Different Distances Inside the Bin During Storage at "La China" Facility

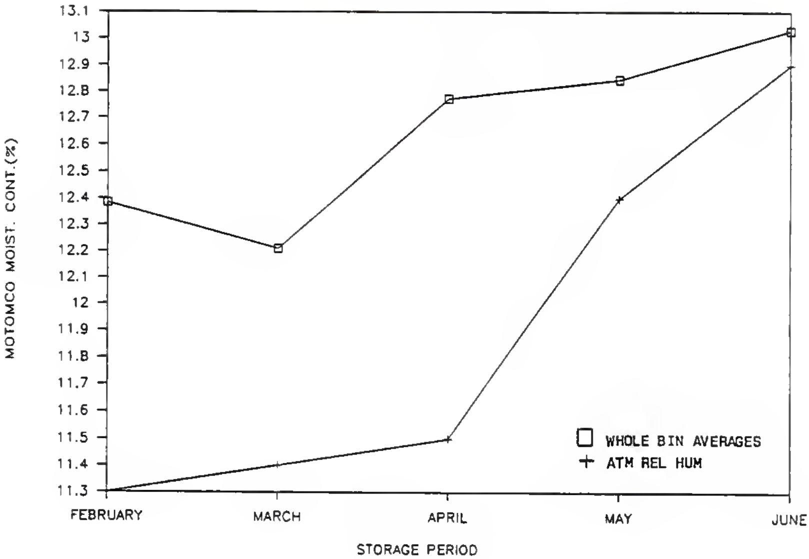


Figure 10. Grain Motomco Moisture Content (Monthly Averages) of the Whole Bin During Storage at "La China" Facility

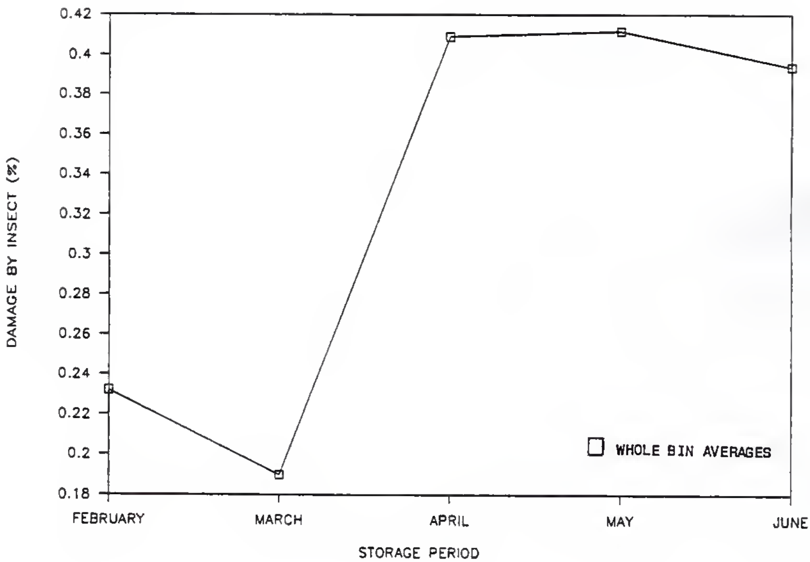


Figure 11. Grain Damage by Insect (Monthly Averages) of the Whole Bin During Storage at "La China" Facility

Level 3 showed the maximum differential in March (0.5% of moisture content) between distance 1 and 3. Distance 3 had the highest values in March, April, May, and June.

Damage by Insects. Whole bin averages showed a decreasing tendency from February to March, with a sharp increase from March to April (from 0.19% to 0.41%), this being the largest differential. The final value was 0.39% in June (Figure 11).

Terraba Plant. The 0.32 percent dry matter loss calculated in the grain stored at the Terraba plant is very small, practically negligible. The analysis of the quality of this grain shows that very few significant changes took place during the storage period. In this sense, the average percentage of grain damaged by insects did not show any statistically significant differences when compared to any of the sampling points in the conditioning process. In support of this fact, it was later found that no significant change occurred during the storage period in the average grain bulk density (the initial value was 75.2 kg/hl or 58.47 lb/bu and the final value was 75.45 kg/hl or 58.67 lb/bu. In addition, the average percentage of impurities did not increase during the storage period (Table 5).

The level of aflatoxin in ppb did not change significantly between the time the grain arrived at the hopper and the time it was unloaded from the bin at the end of the storage period. The initial average level was 69 ppb and the final average level was 31 ppb (Table 5).

The cleaning machine in Terraba removed a statistically significant amount of impurities (the average value changed from 0.77 percent to 0.43 percent) (Table 5).

Some cooling and drying of the grain took place during the storage period. The average grain temperature decreased from 130.6^{o}F (54.8^{o}C) to 94.2^{o}F (34.5^{o}C) and the average oven moisture content decreased from 12.31 percent to 11.38 percent (the change in moisture content was not statistically significant). A total of 37 hours of aeration were applied to the grain during the storage period (all the hours were applied in the first storage month).

There were no significant differences between the initial and final levels of the average percentage of broken kernels and the average damage by molds (Table 5).

From Figures 12 through 20 and also Tables 13-AIII through 24-AIII in Appendix III, it is possible to describe how the changes in temperature, moisture content, and damage by insects occurred during the storage period in the Terraba plant.

Temperature. Differentials between average grain temperature and atmospheric temperature were greater than 10^{o}F (5.5^{o}C) in all figures for the months of June (13^{o}F or 7.2^{o}C) and July (15^{o}F or 8.3^{o}C) (Figure 15).

The smallest differential was in May (1^{o}F or 0.5^{o}C) and the largest was in July (15^{o}F or 8.3^{o}C) (Figure 15).

Temperature differentials between levels, between radii in a level, and between distances in a level were never equal to or greater than 10^{o}F (5.5^{o}C) for any month (for the average values) (Figures 12, 13, and 14).

Practically, there was no difference (1^{o}F or less) between the average temperature of the three levels for the storage months (Figure 12).

Average temperature for radius 1 (eastern side of the bin's wall exposed to sunlight) in all levels tended to be higher than those for the other radii for the months of March and April (Figure 13).

From May until July, the average temperatures for radius 3 (northwestern side of the bin's wall, exposed to sunlight), were higher almost all the time than those for the other two radii. However, the differentials were never equal to or greater than $10^{o}F$ or $5.5^{o}C$ ($4^{o}F$ maximum, Figure 13).

In all the levels for all the storage months, the average temperatures for distance 1 (the closest location to the bin's central point - 2.1 meters apart) were higher than those of the other two distances. However, the differential never reached a value equal to or greater than $10^{o}F$ or $5.5^{o}C$ ($4^{o}F$ was the maximum, Figure 14).

In general, the decreasing tendency of the ambient temperature was followed by the grain temperature from March to May but after that, grain temperature increased sharply in June and then in July, while ambient temperature continued decreasing (Figure 15).

Motomco Moisture Content. The whole bin average increased from the lowest value in March (11.2%) up to the highest value in June (11.9%) to then decrease to a final value in July (11.3%). So, the largest differential was 0.7% of moisture content, between the months of March and June (Figure 19).

The general variations inside the bin followed the increasing tendency of the atmospheric relative humidity during March (83%), April (86%), and May (90%). After this, the values of relative humidity decreased to 89% for the months of June and July but the values of moisture

content kept increasing until they reached the maximum value in June (Figure 19).

The variations by level showed the same pattern as the general variations, with the values of level 1 (the closest to the bin's roof) being the highest ones most of the time and the values of level 3 being the lowest ones (Figure 16).

However, the largest differential between those two levels was 0.9% of moisture content in the month of May (from 11.8% to 10.9%) and the smallest differential between the same levels was 0.4% of moisture content in the month of April (from 11.4% to 11.0%, Figure 16)).

The average values by radius over the three different levels showed the following variations (Table 15-AIII).

Level 1 showed the maximum differential in March (1.1% of moisture content) between radius 1 (10.8% - eastern side of the bin's wall) and radius 3 (11.9% - northwestern side of the bin's wall). Radius 3 had the highest values all the time, except in June when 1 had the highest one.

Level 2 showed the maximum differential in March (0.5% of moisture content) between radius 1 (11.2%) and radius 3 (11.7%). Radius 2 had the highest values in April, May, and July. Radius 3 had the highest value in March and 1 did in June.

Level 3 showed the maximum differential (0.4% of moisture content) in May, between radius 2 (11.1%) and 3 (10.7%). Radius 2 had the highest values in May, June, and July. Radius 3 had the highest value in March and 1 in April.

For all levels, radius 1 had an increase - decrease - increase - decrease behavior.

For all levels, radius 2 and 3 had a decrease - increase - decrease behavior.

The average values by distance over the three levels showed the following variations (Table 16-AIII).

For Level 1, the highest values were reported in this order from up to down: distance 3, distance 1, and distance 2. The largest differential was in March (0.6% of moisture content) between distance 3 (11.7%) and distance 2.

For Level 2, the highest values were reported in the following order from up to down: for May, June, and July, distance 3, distance 1, and distance 2. In March, the order was 2, 3, 1, and in April, it was 3, 2, 1.

The largest differential occurred in July (0.6% of moisture content) between distance 2 (11.1%) and distance 3 (11.7%).

For Level 3, the highest values were reported in the following order from up to down: distance 3, distance 2 and distance 1, except for March when the order was 1, 3, 2.

The largest differential occurred in May (0.8% of moisture content) between distance 1 (10.6%) and distance 3 (11.4%).

Damage by insects. Whole bin averages showed a gradually increasing tendency from a minimum in March (0.09%) up to a maximum in July (0.37%). The largest differential was between July and March (0.28% of damage by insects), but there was a sharp increase from March (0.09%) to April (0.22%, Figure 20).

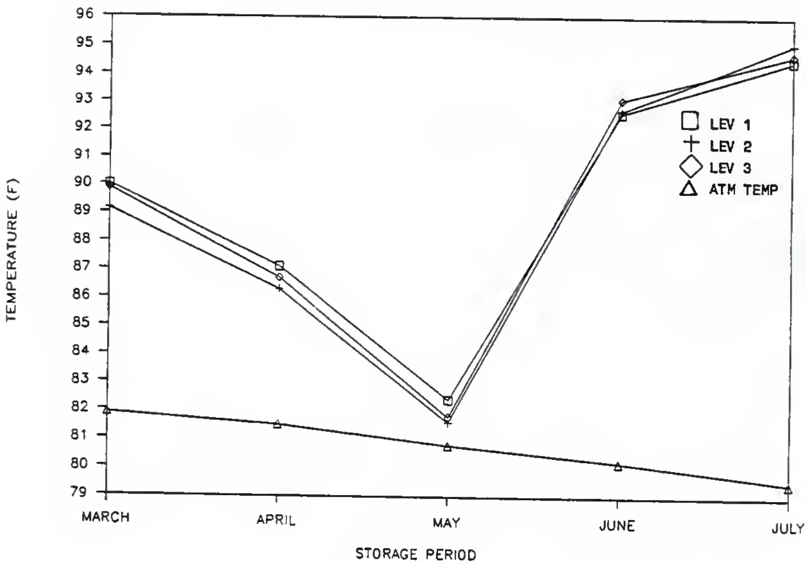


Figure 12. Grain Temperature (Monthly Averages) at Different Levels Inside the Bin During Storage at "Terraba" Facility

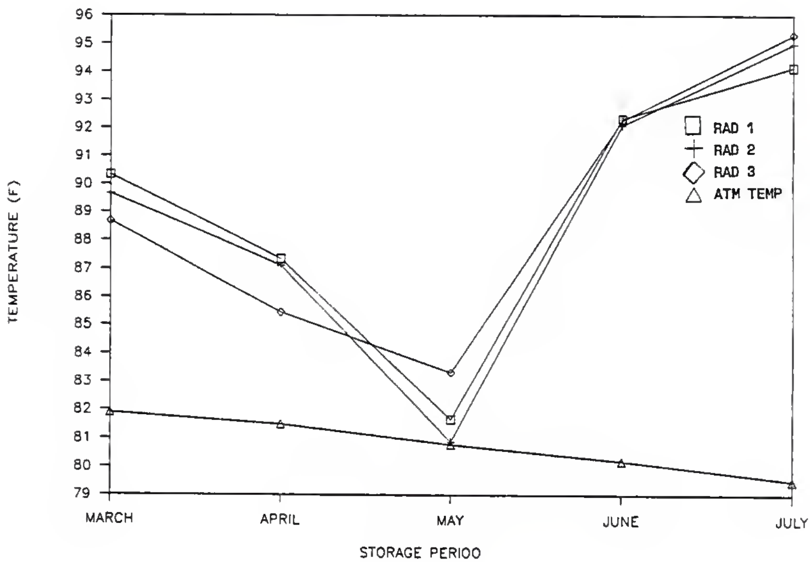


Figure 13. Grain Temperature (Monthly Averages) at Different Radii Inside the Bin During Storage at "Terraba" Facility

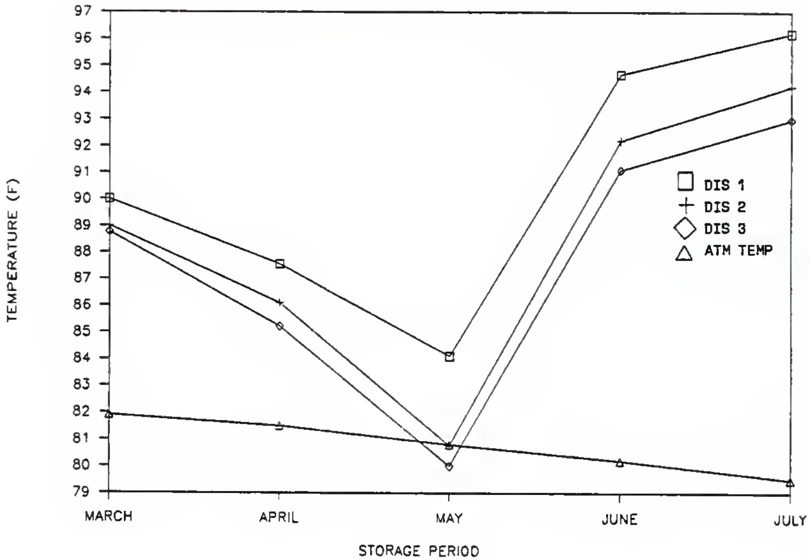


Figure 14. Grain Temperature (Monthly Averages) at Different Distances Inside the Bin During Storage at "Terraba" Facility

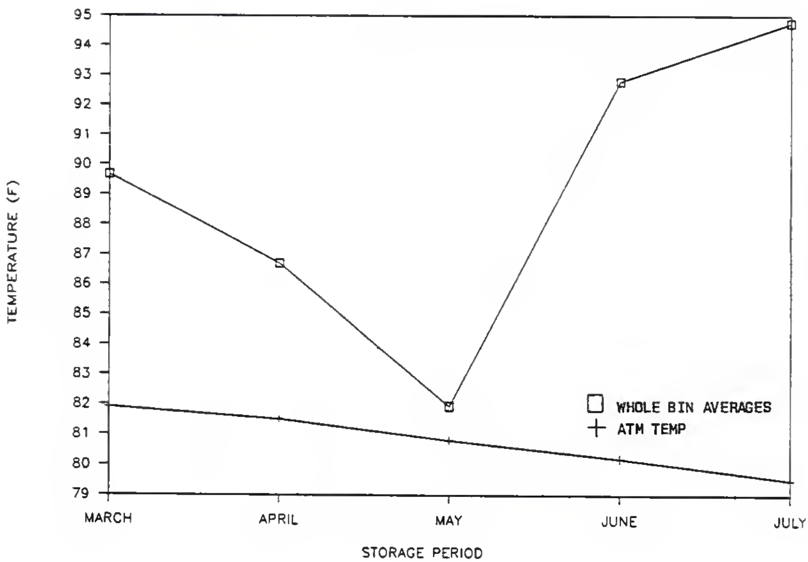


Figure 15. Grain Temperature (Monthly Averages) for the Whole Bin During Storage at "Terraba" Facility

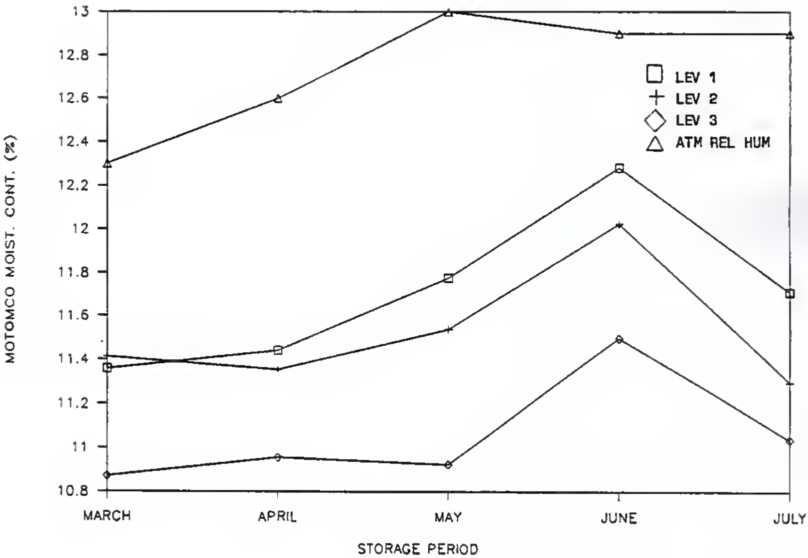


Figure 16. Grain Motomco Moisture Content (Monthly Averages) at Different Levels Inside the Bin During Storage at "Terraba" Facility

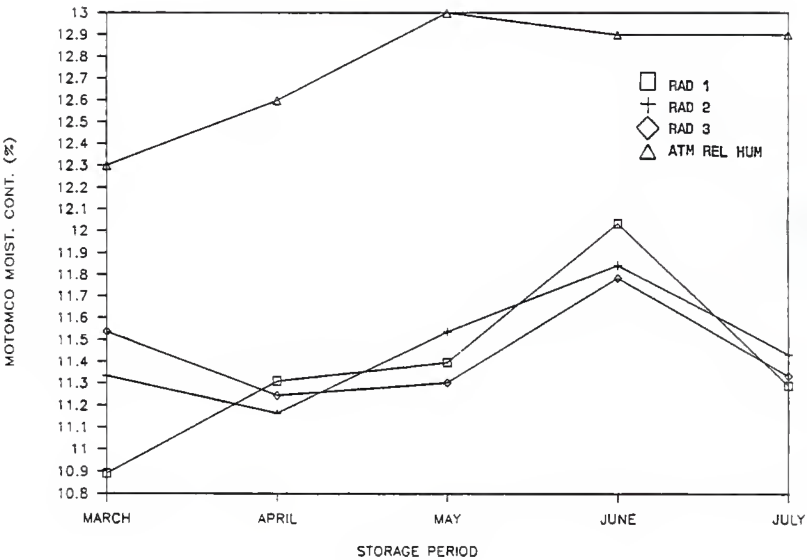


Figure 17. Grain Motomco Moisture Content (Monthly Averages) at Different Radii Inside the Bin During Storage at "Terraba" Facility

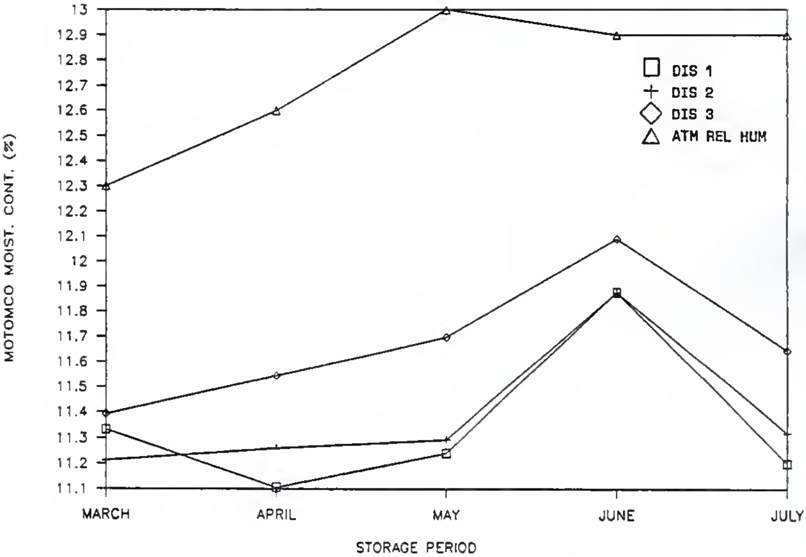


Figure 18. Grain Motomco Moisture Content (Monthly Averages) at Different Distances Inside the Bin During Storage at "Terraba" Facility

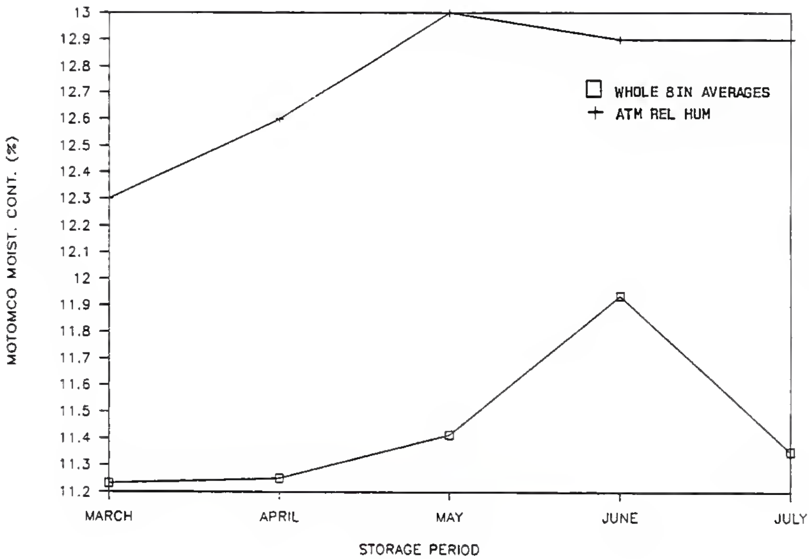


Figure 19. Grain Motomco Moisture Content (Monthly Averages) for the Whole Bin During Storage at "Terraba" Facility

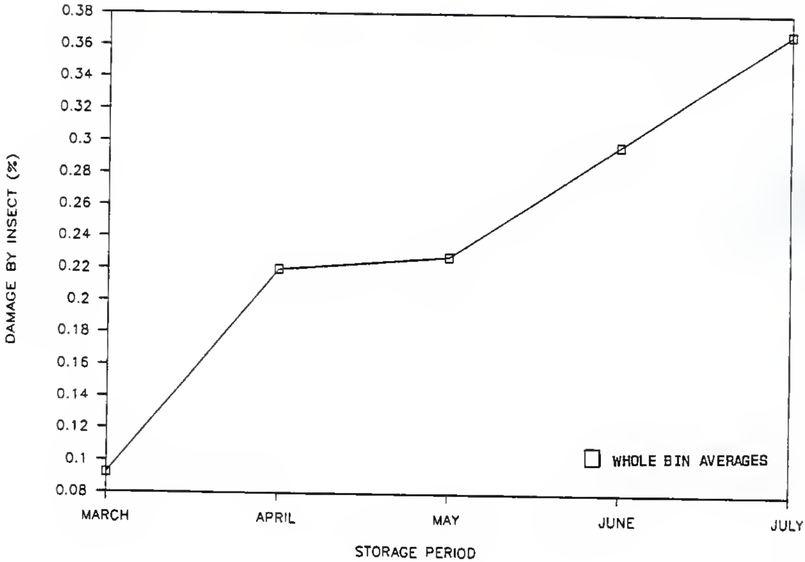


Figure 20. Grain Damage by Insect (Monthly Averages) of the Whole Bin During Storage at "Terraba" Facility

Statistical Analysis

Two types of statistical analyses were applied using the SAS program (Statistical Analysis System). The first one took into account the variation of the grain parameters (temperature, moisture content, density, impurities, broken kernels, damage by insects, damage by molds, and aflatoxins level) at every stage of the conditioning and storage processes (initial and final condition of storage) and it included the One-Way Analysis of Variance (ANOVA), the Least Significant Difference Procedure (LSD), and the LS means. The second type of analysis included the in-bin variations of the parameters during the 4-month storage period. The analysis was based on the calculation of the linear (CL) and quadratic (CQ) components of the observations of both elevators for La China (Environment 1) and Térraba (Environment 2) for three of the parameters measured for the grain during the storage period (temperature, Motomco moisture content, and percentage of damage by insects). CL and CQ were calculated using orthogonal polynomial coefficients under two different conditions, with five coefficients, using the data corresponding to the initial condition of the grain inside the bin and to each of the 4 months of storage, and with four coefficients, using the data corresponding to each of the 4 months of storage, ignoring the initial condition which was the one with more missing values.

The coefficients were taken from Table A19, Snedecor and Cochran (1982).

Several models were tested to find a suitable one able to explain the variations in the data with the help of the Statistical Analysis

System (SAS) through the command GLM because there were some missing values that caused the data to be unbalanced. The subroutine GLM was applied to the whole set of observations of the two elevators together (54 observations for temperature and 60 observations for each of the other two parameters mentioned above) and also to each elevator separately. The final objective was to know when the variations of the parameters of the grain analyzed within the bin showed statistically significant differences and whether or not these differences presented linear or quadratic trends. For our purposes $\alpha = 0.10$ was the threshold of significance (any value above 0.10 will not be significant). It was decided to work with a "mixed" type model in which the environments (the grain elevators) were random (in the sense of being a sample of a region of Costa Rica) and the levels, radii and distances, were fixed. For a fixed model, the variance (σ^2) is appropriate as an error term and this is consistent with the assumption of the GLM procedure. The most relevant parts of the outputs of this analysis are enclosed in Appendix V. The following is a summary of the statistically significant findings of the analysis performed but please see Appendix V first.

Grain temperature. A quadratic trend for the radial variations of grain temperature within levels within environments for the 5-month data set. Also a linear trend for the radial variations with a weaker quadratic component for the 4-month data set (Figures 4 and 13).

Motomco Moisture Content. A linear trend for the variations of this parameter by distance within levels and by distance within environments, for both types of data sets (4- and 5-month sets) (Figures 9 and 18).

Also a less strong tendency for linear radial variations for both types of data sets.

Damage by insects. A quadratic trend for the variation of damage by insect, taking place by distance within environments and by levels, for the 4-month data sets. Also a weaker quadratic tendency for the 5-month data set by distance and by radius within environnments (Figures 11 and 20).

Discussion

The general initial condition of grain observed at La China and Terraba was similar (Table 4), except for the higher temperature at Terraba (130.6°F or 54.7°C compared to 106°F or 41.1°C for La China) and the lower oven moisture content at Terraba (12.31 percent compared to 13.08 percent for La China). It is important to note that the lower standard deviation of the oven moisture content values for La China indicates that the moisture content was more homogeneous for the grain that entered the bin at La China than for the grain under study at Terraba. However, the higher standard deviation of the grain temperature values at La China (5.4 compared to 3.7 at Terraba) indicate that temperature was more homogeneous at Terraba than at La China when the grain entered the bin. The temperature differentials at La China were sometimes as high as 20°F (11.1°C), which shows that the grain left the drying process under temperature conditions that varied considerably.

From Table 3, the values of the standard deviations of the temperatures and moisture contents help to analyze the distribution of those

parameters in the grain stored inside the bin. Right after the bin filling process, the temperature values at La China showed a higher standard deviation (3.2 compared to 1.0 at Terraba) that indicates a nonhomogeneous distribution of grain temperatures with differentials as high as 10 ($5.5^{o}C$) and $15^{o}F$ ($8.3^{o}C$), which are not recommended at all. The Motomco moisture content values in this case showed a lower standard deviation for La China (0.30 compared to 0.48 for Terraba) that indicates a less homogeneous moisture distribution at Terraba, but with the advantage of lower average moisture contents (11.25 percent at Terraba and 12.38 percent at La China).

After the first month of storage, the distribution of temperatures and moisture contents tended to be fairly homogeneous at both elevators (Table 3).

The maximum standard deviation for the temperature values during the storage period at La China was 2.2 in the third month of storage (May), and at Terraba it was 1.5 during the second month (April). The maximum standard deviation for the moisture content values was 0.63 at La China for the fourth month (June), and 0.49 at Terraba during the second and third months (April and May).

For both elevators, distance 1 (the closest to the center of the bin) showed the highest temperatures, which indicates a probable concentration of foreign material around the center of the bin that prevents the aeration air from removing the heat in that area. This also shows a problem of distribution of the impurities inside the bin (the bin does

not have a grain spreader) and also a lack of effectiveness in the cleaning machines, especially at La China.

For both elevators, level 1 (the closest to the bin's roof) showed the highest temperature and moisture values which suggest a problem of condensation and slight heating on the top surface of the grain, mainly due to convection air currents inside the bin caused by the temperature differentials observed at the beginning of the storage period.

Another common observation for both elevators was that radius 1 (the one in line with the sunlight's side of the bin's wall) always showed a higher temperature than the other two as a consequence of the more direct solar radiation received.

The aeration practices in the two elevators were very different. At the La China plant, they aerated the grain intensively after the bin filling process (48 hours during the first month), but more than 50 percent of those hours were applied at ambient temperatures of 81, 82, 85 and 84°F (27.2, 27.8, 29.4, and 28.8°C), which might have had an effect on the heating the grain underwent from February to March (Figure 6). This aeration time under those rather dry conditions (55 percent average relative humidity) caused the moisture content to decrease from 12.38 to 12.28 percent during the month of March. At the end of April, after 17 aeration hours during that month, the grain temperature decreased because the atmospheric temperature had also decreased, and the higher average ambient relative humidity (59 percent) contributed to the rise in moisture content as can be seen in Figure 10. In May, the average grain temperature showed a sharp decrease (down to 70°F or 21.1°C) below the

average ambient temperature (72°F or 22.2°C) after only 13 aeration hours at average conditions of 79°F (26.1°C) and 57.5 percent relative humidity, which obviously does not justify the sharp decrease in the grain temperature. Under these circumstances, it is very likely that grain temperature measurements for the month of May were biased due to a lack of calibration of the thermometer. A decrease in the temperature was expected for May (because the ambient temperature continued its decreasing tendency) but not to such a high degree. A very small increase in moisture content occurred during this month. Finally, at the end of June, after 22 aeration hours with average conditions of 81°F (27.2°C) and 60 percent relative humidity, the grain temperature increased again to 79°F (26.1°C) and the moisture content increased to 13.03 percent.

The damage by insects (Figure 11) showed a sharp increase from March to April as a result of insect activity closely related to the heating process inside the bin at the end of March.

The aeration time at Terraba was concentrated in the first month of storage, especially after the bin filling process was over. Thirty-seven aeration hours were applied during the month of March, with average conditions of 85°F (29.4°C) and 75 percent relative humidity. The aeration process was successful in cooling the grain to 87°F (30.5°C) by the end of April (Figure 15) but the moisture content increased slightly to 11.25 percent (Figure 19). With no aeration involved and a decrease in ambient temperature (81°F or 27.2°C), the grain temperature decreased even more to 82°F (27.8°C) at the end of May. An increasing ambient relative humidity (90 percent) caused the grain moisture content to

increase to 11.41 percent. Though the average ambient temperature kept decreasing in June (80°F or 26.6°C) and July (79.8°F or 26.5°C), the average grain temperature increased sharply to 93°F (33.8°C) in June and 95°F (35°C) in July, a behavior which is closely related to the increase in insect activity denoted by the increase in damage by insects observed in the grain in June and July (Figure 20). The average moisture content increased in June to 11.94 percent and tben decreased to 11.35 percent, closely following the trend of the ambient relative humidity (Figure 19).

In general, at both elevators, it is understood that grain stored while still hot needs intensive aeration, but then it is also clear that the criterion for deciding on aeration does not take into account important indicators such as grain temperature (there are no temperature sensors inside the bins), ambient temperature, and relative humidity. At La China, on several occasions, the grain was heated with aeration, and at Terraba, aeration was absent when the grain was heating during June and July and urgently needed aeration. At La China tbe airflow rate used was approximately 1/2 cfm/bushel (0.4 $m^3/min/m^3$ and at Terraba it was 1/3 cfm/bushel (0.2 $m^3/min/m^3$), which is rather high for tbe low moisture contents of the grain involved in the experiments (1/10 to 1/20 cfm/-bushel or 0.04 to 0.08 $m^3/min/m^3$ is the recommendation from the United States Department of Agriculture, 1985).

Though it is clear that the experiments were completely independent and that conditions at La China were very different from those at Terraba, observations made at tbe elevators during the 4-month period can help explain the difference in loss from one elevator to the other.

Two main differences regarding grain conservation practices were observed. First, at Terraba they sprayed the empty bin with a known mixture of DEDEVAP 500 EC and ACTELLIC 50 before putting the grain inside. At La China, they did not. Second, at both elevators, the grain was attacked mainly by two types of insects -- Sitophilus and Tribolium.

At both plants, they fumigated the grain twice during the 4-month storage period, but at Terraba the fumigation was performed from the surface of the grain by inserting Phostoxin tablets over the entire area under the grain surface, and also through the aeration fan at the bottom of the bin. At La China, fumigation was done only through the fan. At both plants, Sitophilus was controlled, but at La China, Tribolium always survived the fumigation. To a lesser degree, Tribolium also survived the fumigations at Terraba. The higher airflow rate at La China (1/2 CFM/-bushel compared to 1/3 CFM/bushel at Terraba) is also a factor that probably made fumigation less effective at La China.

This confirms that the difference in conservation practices seemed to be the main reason for which the grain at La China suffered a higher loss in quantity and quality than the grain at Terraba.

It is important to mention also that the statistical analysis performed was the best effort possible within the limitations inherent to the research, which allowed no possibility of having replications of the bins under study at each elevator. This would have implied the duplication of the resources and work involved in the research and it would have made everything twice as difficult and practically impossible.

The trends identified by the models tested are more useful when they are linear (case of the moisture content) and less practical when they

are quadratic (case of the temperature and damage by insects). The statistical models match the actual data trends in a clear way.

Application of the Bin-Volumetric Method

Direct grain loss assessment is very expensive, complicated, and impractical during the normal operation of an elevator. This study tested the so-called bin-volumetric method (calculation of the initial and final grain weight through the initial and final volume and bulk density inside the bin) as a possible practical method for grain loss assessment during the storage period. The volumetric procedure was applied in two different ways. First, the difference in wet grain volumetric weights was calculated between the initial and final conditions, and second, the difference in dry matter volumetric weights was calculated between the initial and final condition. The results were as follows:

La China	
Direct Loss Assessment	1.68%
Wet Grain Volumetric Method	1.38%
Dry Matter Volumetric Method	1.17%
Terraba	
Direct Loss Assessment	0.32%
Wet Grain Volumetric Method	0.38%
Dry Matter Volumetric Method	0.58%

As can be seen from the above figures, the wet grain volumetric method value was especially close to the direct loss assessment value in

both cases. This is a very important finding with immediate practical application for CNP and similar entities, provided the grain surface is leveled after filling the storage bin and the grain bulk density values are measured. Developing countries have an important alternative to measure grain losses in a practical way through the use of the bin-volumetric method.

The parameters involved in the calculation of the volumetric weights are shown in the results section (Table 3) and they include internal bin diameter and height, initial and final grain surface levels, bulk density, and oven moisture content values.

Table 7 shows the steps of the calculation process.

Results of the Drying and Cleaning Performance Tests

The results presented here correspond to the data collected at the two above-mentioned CNP plants in Costa Rica and Gary Gilbert's grain elevator in Clay Center, Kansas (December 1986).

The purpose of the tests was to examine the drying performance of three grain dryers based on the current practices found in the different grain elevators, using clean and unclean lots of white corn (in Costa Rica) and milo (in Kansas). The parameters measured during the tests were average atmospheric temperature, average relative humidity, average plenum air temperature, average outlet air temperature, average grain temperature range, average grain moisture content range, heat input to heat the drying air, average energy to evaporate 1 kg of water, drying

TABLE 7. RESULTS OF THE GRAIN LOSS CALCULATION PROCESS BY THE BIN-VOLUMETIC METHOD

ITEM	LA CHINA	TERRABA
	VALUE	VALUE
Initial Bulk Density (after filling)	760.2 Kg/m^3	766.1 Kg/m^3
Initial Oven Moisture Content (after filling)	12.45%	11.46%
Initial Grain Level (after filling)	6.605 m	7.45 m
Initial Volume of Grain	1,101.96 m^3	1,238.71 m^3
Initial Wet Volumetric Weight	837,712.29 Kg	948,975.73 Kg
Initial Dry Matter Weight	733,417.11 Kg	840,233 Kg
Final Bulk Density (fourth sampling)	756 Kg/m^3	761.6 Kg/m^3
Final Oven Moisture Content (fourth sampling)	12.26%	11.63%
Final Grain Level (fourth sampling)	6.55 m	7.465 m
Final Volume of Grain	1,092.78 m^3	1,241.21 m^3
Final Wet Volumetric Weight	826,141.68 Kg	945,306.43 Kg
Final Dry Matter Weight	724,856.71 Kg	835,367 Kg
Wet Weight Difference	11,570.61 Kg	3,668.7 Kg
PERCENTAGE OF WET LOSS	1.38%	0.38%
Dry Matter Weight Difference	8,560.4 Kg	4,856 Kg
PERCENTAGE OF DRY MATTER LOSS	1.17%	0.58%

time, drying rate, and thermal efficiency[1].

The performance of the grain cleaner used at each elevator was also of interest. The parameters measured in this case were cleaning time, cleaner design capacity, cleaner working capacity, cleaner efficiency, power input, cleaning rate, and grain moisture content.

Table 8 describes the data on the performances of the cleaners for the three elevators involved.

Tables 9 through 11 illustrate the data on the drying performance tests for elevators at La China, Terraba, and Clay Center.

Discussion of Drying and Cleaning Performance Tests

The purpose of these tests was to examine the drying efficiency of three grain dryers based on the current practices found in the different elevators, using clean and unclean lots of white corn (in Costa Rica) and milo (in Kansas). This implied that the drying settings during the experiments varied considerably and that the original conditions for grain moisture content, plenum air temperature, atmospheric parameters, and others were not the same in all the tests. However, the results obtained are useful because they show important facts about performance of the grain dryers and cleaners, no matter the location. With clean grain, two tests were performed at the La China plant (Costa Rica), one at the Terraba plant (Costa Rica), and two at the Clay Center elevator

[1] Chang, 1977.

TABLE 8. CLEANING PARAMETERS ON THE GRAIN LOTS USED FOR THE DRYING PERFORMANCE TESTS WITH CLEAN CORN AND CLEAN MILO

PARAMETER	LA CHINA[1] CLEANER: SCALPERATOR CARTER DAY WHITE CORN, FEB & JUNE 1987	
	TRIAL 1	TRIAL 2
Cleaning Time (hr)	0.63	3.35
Theor. Capacity (kg grain/hr)	89,813	89,813
Working Capacity (kg grain/hr)	28,195	17,765
Cleaner Efficiency (%)	31	20
Power Input (kw)	2.2	2.1
Cleaning Rate (kg lifting/hr)	79	51
Moisture Content (% w.b.)	13.77	24.66

1 Screen size: 24 x 76 inches; orifice size: 1/2 x 3/4 inches; capacity: 3,300 bu/hr

TABLE 8. (Continued)

PARAMETER	TERRABA[1] CLEANER: SCALPERATOR CARTER DAY WHITE CORN, MARCH 1987 TRIAL 1	TRIAL 2
Cleaning Time (hr)	1.8	2.2
Theor. Capacity (kg grain/hr)	55,696	55,696
Working Capacity (kg grain/hr)	23,372	23,094
Cleaner Efficiency (%)	42	41
Power Input (kw)	2	2
Cleaning Rate (kg lifting/hr)	73	73
Moisture Content (% w.b.)	13.86	14.76

1 Screen size: 24 x 60 inches; orifice size: 1/2 x 3/4 inches; capacity: 2,046 bu/hr

TABLE 8. (Continued)

PARAMETER		CLAY CENTER CLEANER: KICE CK-84 RH KANSAS MILO, DEC 1986	
		TRIAL 1	TRIAL 2
Cleaning Time	(hr)	0.44	0.49
Theor. Capacity	(kg grain/hr)	50,817	50,817
Working Capacity	(kg grain/hr)	53,971	54,486
Cleaner Efficiency	(%)	106	107
Power Input	(kw)	11.1	11.2
Cleaning Rate	(kg lifting/hr)	514	518
Moisture Content	(% w.b.)	15.68	16.06

TABLE 9. DRYING PERFORMANCE TESTS - ELEVATOR LA CHINA, DRYER: MATHEWS 900E, GRAIN: WHITE CORN, FEBRUARY, JUNE, and JULY 1987

PARAMETERS		TRIAL 1	
		CLEAN	UNCLEAN
Av Atm Temp	(^{o}C)	28.3	30.9
Av Rel Humidity	(%)	48	43
Av Plenum Temp	(^{o}C)	48.8	57.1
Av Outlet Temp	(^{o}C)	31.7	32.4
Av Grain Temp Range	(^{o}C)	25.3 to 38.6	25 to 45.9
Av Grain Moist Range	(% w.b.)	13.7 to 12.88	13.46 to 12.73
Drying Time	(HR)	1.53	1.71
Total Energy Consumption (Fuel & Electricity)	(KW)	288	310
Energy to Evap Water	$\left(\frac{KJ}{kg\ H_2O}\right)$	8,115	11,199
Drying Rate	$\left(\frac{kg\ H_2O}{HR}\right)$	127	99
Thermal Efficiency	(%)	24	15

TABLE 9. (Continued)

PARAMETERS		TRIAL 2 CLEAN	TRIAL 2 UNCLEAN
Av Atm Temp	(°C)	25.3	26.9
Av Rel Humidity	(%)	72.6	59.8
Av Plenum Temp	(°C)	62.5[1]	65.3
Av Outlet Temp	(°C)	37.5	36
Av Grain Temp Range	(°C)	29.7 to 66.8	30.3 to 58
Av Grain Moist Range	(% w.b.)	24.66 to 15.42	20.85 to 14.88
Drying Time	(HR)	12.31	4.74
Total Energy Consumption (Fuel & Electricity)	(KW)	576	526
Energy to Evap Water	$\left(\frac{KJ}{kg\ H_2O}\right)$	3,814	5,171
Drying Rate	$\left(\frac{kg\ H_2O}{HR}\right)$	544	366
Thermal Efficiency	(%)	61	42

1 Wrong temperature reading, lower than the final grain temperature.

TABLE 10. DRYING PERFORMANCE TESTS - ELEVATOR TERRABA, DRYER: BERICO 940E, GRAIN: WHITE CORN, MARCH 1987

PARAMETERS		TRIAL 1	
		CLEAN	UNCLEAN
Av Atm Temp	(°C)	26.6	31.1
Av Rel Humidity	(%)	87	63
Av Plenum Temp	(°C)	72.2	76.6
Av Outlet Temp	(°C)	37.2	38.3
Av Grain Temp Range	(°C)	30.6 to 52.9	31 to 49.4
Av Grain Moist Range	(% w.b.)	13.86 to 12.33	14.31 to 12.88
Drying Time	(HR)	1.95	2.1
Total Energy Consumption (Fuel & Electricity)	(KW)	539	518
Energy to Evap Water	$\left(\frac{KJ}{kg\ H_2O}\right)$	5,139	6,053
Drying Rate	$\left(\frac{kg\ H_2O}{HR}\right)$	377	308
Thermal Efficiency	(%)	41	33

TABLE 11. DRYING PERFORMANCE TESTS - GARY GILBERT'S ELEVATOR, DRYER: BUTLER KAN SUN, GRAIN: KANSAS MILO, DECEMBER 1986

PARAMETERS		TRIAL 1 CLEAN	TRIAL 1 UNCLEAN
Av Atm Temp	(^{o}C)	12	2.6
Av Rel Humidity	(%)	46	59.5
Av Plenum Temp	(^{o}C)	119	118
Av Outlet Temp	(^{o}C)	48.8	31
Av Grain Temp Range	(^{o}C)	13.7 to 28.3	8.7 to 27.1
Av Grain Moist Range	(% w.b.)	15.68 to 13.33	15.66 to 13.92
Drying Time	(HR)	2.0	2.25
Total Energy Consumption (Fuel & Electricity)	(KW)	232	222
Energy to Evap Water	$\left(\frac{KJ}{kg\ H_2O}\right)$	2,595	2,951
Drying Rate	$\left(\frac{kg\ H_2O}{HR}\right)$	322	271
Thermal Efficiency	(%)	64	56

TABLE 11. (Continued)

PARAMETERS		TRIAL 2	
		CLEAN	UNCLEAN
Av Atm Temp	(^{o}C)	14.2	
Av Rel Humidity	(%)	34.1	
Av Plenum Temp	(^{o}C)	120.4	
Av Outlet Temp	(^{o}C)	32.4	
Av Grain Temp Range	(^{o}C)	12.4 to 29.4	
Av Grain Moist Range	(% w.b.)	16.06 to 13.92	
Drying Time	(HR)	2.0	
Total Energy Consumption (Fuel & Electricity)	(KW)	435	
Energy to Evap Water	$\left(\frac{KJ}{kg\ H_2O}\right)$	2,532	
Drying Rate	$\left(\frac{kg\ H_2O}{HR}\right)$	309	
Thermal Efficiency	(%)	64	

(Kansas). With unclean corn, two tests were performed at the La China plant, one at the Térraba plant, and one at the Clay Center elevator.

Cleaning data. La China and Térraba plants have the same type of grain cleaner (Scalperator Carter Day) with different screen sizes (Table 8), designed for a capacity of 89,813 kg/hr (La China) and 55,696 kg/hr (Térraba). Table 8 shows that the working capacities of the cleaner at La China (28,195 and 17,765 kg/hr) represented only 31 and 20 percent, respectively, of the design capacity (89,813 kg/hr). In Térraha, the working capacities recorded (23,372 and 23,094 kg/hr) represented 42 and 41 percent, respectively, of the design capacity (55,696 kg/hr). The power inputs in La China's cleaner (2.2 and 2.1 KW) were 10 and 5 percent higher than the power input in Térraba's cleaner (2.0 KW). In addition, the lifting removal capacity or cleaning rate in Térraba (73 kg/hr) was 1.4 times higher than the one in La China (51 kg/hr) in trial No. 2. In both elevators the grain with lower moisture contents was cleaned faster. Though generalizations can not be made, there is clear evidence to conclude that the two grain cleaners (but especially the one at La China) are not operating adequately and require revision of the main capacity variables which are the inlet opening, speed of rotation, diameter of the screen's orifices, size of the screen, and cleanliness of the machine.

The grain cleaner at Clay Center, Kansas, showed working capacities (53,971 and 54,486 kg/hr) which were 6.2 and 7.2 percent higher than the design capacity (50,817 kg/hr). The power inputs (11.1 and 11.2 KW) were 5.4 times higher than the average value for the Costa Rican plants (2.05 KW), hut with a cleaning rate 8 times higher than the one at La China

and seven times higher than the one at Térraba. The data indicated in general that the grain cleaner in Clay Center worked under acceptable conditions during the tests.

Drying data - La China. Table 9 shows, for the clean grain tests, thermal efficiencies of 24 percent (Trial 1) and 61 percent (Trial 2); drying rates of 127 kg water/hr (Trial 1) and 544 kg water/hr (Trial 2); and energy consumptions of 8,115 KJ/kg water (Trial 1) and 3,814 KJ/kg water (Trial 2). The lowest thermal efficiency among the trials (24 percent for Trial 1) corresponded to the case with the smallest moisture removal (from 13.77 to 12.88 percent). The highest thermal efficiency (61 percent for Trial 2) corresponded to the case with the largest moisture removal (from 24.66 to 15.42 percent). The difference in energy consumption per kg of water evaporated between the two tests described (Trial 1 required 113 percent more energy than Trial 2) is explained by the fact that the moisture removal in Trial 1 was done at very low moisture contents where the water left in the kernels is strongly attached (bound water). This is the reason for a much higher efficiency in Trial 2 (61 percent) compared to Trial 1 (24 percent). Final grain temperatures were 38.6°C for Trial 1 and 66.8°C for Trial 2, and the differentials between ambient and plenum temperatures were 20°C in Trial 1 and 37.2°C or more in Trial 2.

Table 9 also shows thermal efficiencies for the unclean corn of 15 percent (Trial 1) and 42 percent (Trial 2), drying rates of 99 kg water/hr (Trial 1) and 366 kg water/hr (Trial 2), and energy consumptions of 11,199 KJ/kg water (Trial 1) and 5,171 KJ/kg water (Trial 2). The

lowest thermal efficiency among the trials (15 percent for Trial 1) corresponded to the case with the smallest moisture removal (from 13.46 to 12.73 percent). The highest thermal efficiency (42 percent for Trial 1) corresponded to the case with the largest moisture removal (from 20.85 to 14.88 percent). The difference in energy consumption per kg of water evaporated between the two tests described (Trial 1 required 116 percent more energy than Trial 2) is explained by the fact that the moisture removal in Trial 1 was done at very low moisture contents (13.46 to 12.73 percent) where the water left in the kernels is strongly attached (bound water). This is the reason for a much higher efficiency in Trial 2 (42 percent) compared to Trial 1 (15 percent). Final grain temperatures were 45.9°C (Trial 1) and 58°C (Trial 2), and the differentials between ambient and plenum temperatures were 26.2°C (Trial 1) and 38.4°C (Trial 2).

In all the cases - even with some differences in the conditions of the atmospheric and drying air - tbe drying process was less efficient with the unclean lots of grain (on the average, unclean corn required 37 percent more energy per kg of water evaporated than the clean corn). In addition, the in-plant handling of the unclean corn caused frequent periods of down time due to grain blockages in the conveyors and bucket elevators. For all the tests, the highest thermal efficiencies corresponded to the cases with the largest moisture removals. For the unclean grain tests, the highest thermal efficiencies corresponded to the cases with the largest moisture removals. For the unclean grain tests, tbe savings in cleaning power (an average of 2.15 KW) were negligible (0.41 to 0.69 percent) compared to the power consumed during tbe drying process (310 KW for Trial 1 and 526 KW for Trial 2).

The final grain temperatures and the differentials between amhient and drying temperatures showed a remarkahle variahility not recommended at all (from 38°C to 66°C for the grain temperature, and from 20°C up to 38°C for the temperature differentials) and that shows different levels of working skills of the dryer operators.

Drying data - Térraba. Table 10 shows a thermal efficiency for the clean grain test of 41 percent, a drying rate of 377 kg water/hr, and an energy consumption of 5,139 KJ/kg water. The moisture removal interval was from 13.86 to 12.33 percent, and the final grain temperature was 52.9°C. The differential between amhient and plenum air temperatures was 45.6°C. From the same table mentioned ahove, the thermal efficiency for the unclean corn test was 33 percent, the drying rate was 308 kg water/-hr, and the energy consumption was 6,053 KJ/kg of water evaporated. The moisture removal interval was from 14.31 to 12.88 percent and the final grain temperature was 49.4°C. The differential hetween amhient and plenum air temperatures was 45.6°C. The comparison of these two tests under similar amhient and drying conditions (rather favorahle to the unclean corn test due to the higher ambient temperature, lower relative humidity, and higher moisture range) shows that the drying of the unclean grain lot was less efficient and required 18 percent more energy per kg of water evaporated than the drying of the clean corn lot. The in-plant handling of the unclean grain also caused prohlems of down time and plugs in the system. The savings of cleaning power for the unclean corn (an average of 2.0 KW) were negligihle (0.39 percent) compared to the power consumed during the unclean grain drying test (518 KW).

Drying data - Clay Center. Table 11 shows thermal efficiencies of 64 percent for the clean grain tests in both trials, drying rates of 322 kg water/hr (Trial 1) and 309 kg water/hr (Trial 2), and energy consumptions of 2,595 KJ/kg water (Trial 1) and 2,532 KJ/kg water (Trial 2). The dryer was slightly more efficient in Trial 2 due to the higher range of moisture contents involved (16.06 to 13.92 percent). That is why Trial 1 required 2.48 percent more energy per pound of water evaporated than Trial 2. Final grain temperatures were 28.3°C (Trial 1) and 29.4°C (Trial 2), and the differentials between ambient and plenum air temperatures were 107°C (Trial 1) and 106.2°C (Trial 2).

Table 11 also shows a thermal efficiency of 56 percent for the only test conducted with unclean milo, a drying rate of 271 kg water/hr, and an energy consumption of 2,951 KJ/kg water. The moisture removal interval was 15.66 to 13.90 percent, and the final grain temperature was 27.1°C.

The drying of the unclean lot of milo was less efficient and required 15 percent more energy per kg of water evaporated than the average value for the clean lots of grain (2,563 KJ/kg water). The in-plant handling of the unclean grain also caused problems of down time and plugs in the grain handling system. The savings of cleaning power for the unclean corn (an average of 11.15 KW) were low (5 percent) compared to the power consumed during the unclean grain drying test. The final grain temperatures were acceptably homogeneous, but air plenum temperatures were high (between 118 and 120°C).

General comments on the drying tests. The tests conducted showed that the drying of the unclean lots of grain (corn and milo) required more energy per kg of water evaporated (37 percent in the La China plant, 18 percent in the Térraba plant, and 15 percent in Gary Gilbert's elevator) than the drying of the clean lots of grain. It is well known that cleanliness of the grain during tbe storage period is important for avoiding insect infestation and mold contamination problems. It is mandatory to note here the importance of the cleanliness of the grain in order to have an easy, smootb, and plug-free in-plant handling of the grain, and to save considerable amounts of energy during the drying process. However, added to this is the possibility (as private elevator managers have been doing in Kansas) of selling the grain lifting (separated by the grain cleaners) for animal feed, at prices as high as 75 percent of the actual grain market price. Lab analysis conducted on several samples of corn lifting from Costa Rica shows raw fiber as high as 27 percent, 6.12 percent ash, 3.06 percent protein, 1.88 percent fat, 0.29 percent phosphorus, and 0.26 percent calcium (combining samples of the three different kinds of lifting the Scalperator Carter Day separates, which are gross, fine, and dust from the cyclone). The specific analysis of each kind of lifting can be obtained from the author. During the drying tests, it was learned that the energy involved during the cleaning process is practically negligible compared with the energy used in tbe drying process. So the possibility of selling the grain lifting carries a direct economic benefit to the grain elevators because it implies no cost if the buyers come to the elevator to purchase the grain lifting.

Finally, it was observed during the tests that when drying grain at very low moisture contents (under 15 percent), the thermal efficiency of the process is so low that the drying operation becomes a waste of energy and time, and other drying alternatives (like dryeration[1]) should be applied.

1 Negrini, O., 1986.

CONCLUSIONS

The grain quality at both the La China and Terraba plants changed during the experimental 4-month storage period. There were statistically significant decreases in grain temperature at both plants during the storage period. There was a statistically significant decrease in oven moisture content only at La China. There were no statistically significant changes in Motomco moisture content at either elevator. There was a statistically significant decrease in bulk density at La China only. There was a statistically significant increase in impurities at La China, but no increase at Terraba. There were no statistically significant changes in broken kernels or mold damage at either plant. There were no statistically significant changes in aflatoxin level at either plant, but the average aflatoxin levels of the grain received at La China and Terraba for the experiment were very high (76 ppb for La China and 69 ppb for Terraba) and not advisable for human consumption. This fact suggests the necessity of a deeper extension work of prevention at the farm level and quality control in the purchasing agencies.

The dry matter losses calculated after the 4-month storage period were 1.68 percent for La China and 0.32 percent for Terraba. The level of these losses and the change in quality parameters at each plant are closely related to the different grain conservation practices applied at each plant. The loss at La China was caused mainly by an insect infestation (*Tribolium* and *Sitophilus*) which was not well controlled with the fumigation practices being used.

The study of the in-bin variations of grain temperature and moisture content during the storage period showed important temperature differentials as a result of the lack of a cooling process for the grain after drying in both plants. Though average differentials between different grain locations inside the bin were not higher than 5.6°C (the grain mass underwent the temperature changes as a whole), during 2 to 3 of the storage months the differentials between the ambient and grain temperature were higher than 5.6°C, which is considered the safety threshold. In both elevators it is understood that grain stored while still hot needs intensive aeration without considering the ambient conditions, but it was clear that the criterion for deciding on application of grain aeration did not take into account important indicators such as grain temperature (there are no sensors inside the bin), ambient temperature and relative humidity. In both elevators, the heating processes were also related to insect activity which the fumigations were not able to control. The airflow rates used for aeration were approximately 0.402 $m^3/min/m^3$ (1/2 cfm/bushel) at La China and 0.268 $m^3/min/m^3$ (1/3 cfm/bushel) at Terraba, which were high for the low moisture contents of the grain involved in the experiments (1/10 to 1/20 cfm/bushel is the recommendation of the U.S. Department of Agriculture, 1985). A statistical analysis using the SAS program was applied to the in-bin variation data on temperature, moisture content, and insect damage to identify linear or quadratic trends in the variations of the parameters mentioned. A quadratic trend was identified for the radial variations of grain temperature within levels within environments and for the damage by insect by distances within environments. A linear trend by distance

within levels and environments was observed for the grain moisture content. The inherent limitation of the statistical analysis was the lack of replications of the bins under the study due to the practical impossibility of having them.

The volumetric method, a practical procedure to estimate grain losses during storage, gave estimations which were very close to the direct loss assessment figures. Using the wet grain option, the volumetric weight losses were 1.38 percent for La China (direct loss was 1.68 percent) and 0.38 percent for Terraba (direct loss was 0.32 percent). The volumetric method of grain loss estimation during storage that was introduced in this study can be easily used at CNP during normal grain storage operations, provided the grain surface is leveled after filling the bin and the grain bulk density variations are available. Developing countries have in this method an attractive alternative to estimate grain losses during the storage period.

The drying and cleaning performance tests conducted showed that the drying of the unclean grain lots (white corn in Costa Rica and milo in Kansas) required more energy per pound of water evaporated (37 percent in the La China plant, 18 percent in the Terraba plant, and 15 percent in Gary Gilbert's elevator) than the drying of the clean grain lots. The tests also noted the importance of grain cleanliness in order to have an easy, smooth, and plug-free in-plant handling of the grain, and to save considerable amounts of energy during the drying process as well. The possibility of selling the grain lifting (separated by the grain cleaners) for animal feed was supported by a laboratory analysis of the nutritive value of three different types of Costa Rican corn lifting that

showed important percentages of raw fiber (27 percent), ash (6.12 percent), and protein (3.06 percent). The cleaning processes during the tests proved to be almost cost-free energy wise and the benefits implied are important. Finally, it was observed that when drying grain at very low moisture contents (under 15 percent), the thermal efficiency of the process is so low that the drying operation becomes a waste of energy and time and other drying alternatives (like dryeration) should be applied.

Though there were some dry matter losses, they were insignificant (much lower than what was expected) under normal grain handling operations, especially under tropical conditions. However, based on the observations of this study, grain handling and storage practices at CNP can be further improved because grain quality is low and often potentially harmful for human and animal consumption. It should be noted that the loss assessment study was based on the dry season crop. Thus, quality changes and grain losses experienced should be considered as the lower values during the overall year-round operation. Therefore, unless a similar type of study with the wet season crop is conducted in the future, the overall situation on grain quality changes and grain loss in CNP operations can not be truly assessed.

RECOMMENDATIONS

The following recommendations were made for improving grain operations at the two CNP plants studied.

1. Cool the grain to a uniform temperature before storing it inside the bin.
2. Check cleaning machines, especially at La China, to test whether they are removing the necessary amount of impurities and undesirable materials. Bad cleaning is synonymous with infestation problems during storage (food for insects and obstacles for aeration). Dryers should also be checked regarding their operation.
3. Review grain preservation methods at each plant and try to standardize the best one, using Terraba's method as a reference (spraying the empty bin, fumigation procedures, and others).
4. Level the grain surface after filling every bin because this facilitates the grain treatment during the storage period (fumigation, aeration, etc.) and also permits the use of the volumetric grain loss estimation method.
5. Cbeck the uniformity of the moisture content of the grain lots leaving the dryer. The more uniform, the less moisture movement during the storage period.
6. Reinforce grain lot rejection criteria when the lots arriving at the purchasing agencies and the plants are already contaminated by molds or infested by insects. The affected lots should not be blended with the uncontaminated lots.

7. Establish technical procedures at each plant for grain aeration inside the bins, taking into account atmospheric conditions (temperature and relative humidity), grain temperature, moisture content, and airflow rate (observed rates were too high).

8. Install systems to monitor grain temperature inside the bin. Thermocouples are the most common.

9. Provide equipment for aflatoxin testing to all CNP plants. At the present time, the La China plant is the only one able to do this. The black light test is not sufficient. However, the most important preventive step should be better mold and aflatoxin control at the farm level.

10. Train technicians or workers involved in moisture measurement with the Motomco moisture meter on the importance of the application of the temperature correction that must be made with every measurement. At the present time, most of them do not know how to do this and they do not even have a thermometer for the measurement.

11. Check CNP's fumigation personnel, especially those called "assistant personnel", on their technical knowledge and safety rules to see whether they are able to substitute for the main technician if necessary.

12. Move the grain as soon as possible from the purchasing agencies to the elevators.

13. Determine the utilization of the facility capacity of both the La China and Terraba plants. During the dry season, the facilities

were considerably under-utilized. Therefore, it is recommended that CNP provide services to the private sector (producers and private grain handlers) during this time.

14. Review and improve the purchasing agencies' physical facilities.
15. Encourage CNP authorities to sell grain lifting as animal feed.
16. Study postharvest grain losses at CNP during the wet season's crop, insisting, this time, on following sufficient grain lots from the purchasing agencies.

RECOMMENDATIONS FOR FUTURE RESEARCH

Future research efforts on this thesis' topic should take into account the following suggestions.

1. Dedicate enough time to assure the necessary political support for the research, especially regarding the amount of grain, the required storage time, and the availability of the multiple resources involved. An unplanned shortening of the storage period, for example, can affect the final results considerably.
2. Devote enough time to communicate the objectives of the project to the technicians and professionals involved so that they can help adequately in the planning of the field tests. The sensitivity of the workers towards the importance of the precision of the measurements of the different parameters is something that needs to be developed through talks and discussions. Check the homogeneity of technical criteria of the lab analysts.
3. Take special care with the temperature measurements of the drying air (plenum temperature) and the outlet air of the grain dryers because they are particularly difficult to calibrate.
4. Measure the grain level inside the bin in at least three points (one over each radius).
5. Lock storage bin gates and disconnect unloading augers in the bins under study to avoid any possibility of alteration of the storage conditions of the grain.

6. Have at least one replication of the bins under study at each location so that the statistical analysis can be conducted adequately. Remember that every replication will double the resources and work required for the research.
7. Follow enough grain lots at the purchasing agencies so that a statistical analysis can be conducted. The following of grain lots in this particular case is difficult because personnel and resources must be mobilized without a regular schedule.
8. Do not rely on third persons (out of the project) to get data on grain weights or other important parameters.

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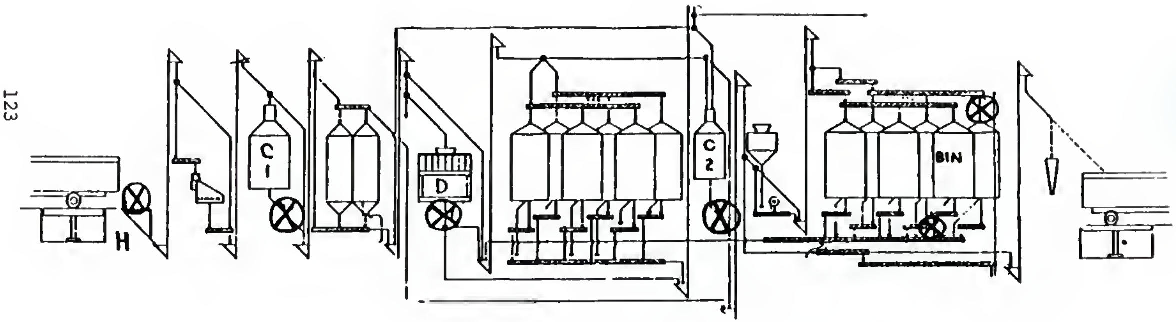
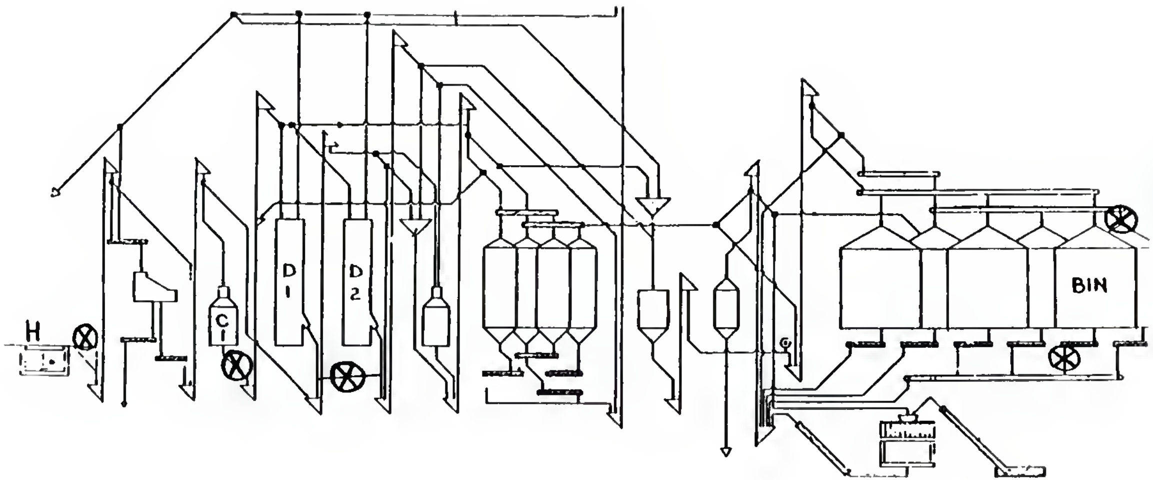
APPENDIX I

FLOW DIAGRAMS



FLOW DIAGRAM - PLANTA LA CHINA



FLOW DIAGRAM - PLANTA TERRABA

APPENDIX II

DATA TABLES ON VARIOUS PARAMETERS EXAMINED

TABLE 1-AII. TEMPERATURE DATA AT LA CHINA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																	
RAW DATA				ELEVATOR: LA CHINA				PARAMETER: TEMPERATURE (°F)									
				GRAIN SAMPLING INSIDE THE BIN													
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
94.2	80.0	80.7	116.6	122.7	C-2	SE-4-7	96	80	100	91	90	84	83	70	77	80	79	86
75.5	79.3	80.8	117.1	102.6	C-5	SE-6-2	80		91	90	88	86	75	67	80	80	78	80
80.0	76.0	81.1	90.5	105.8	C-7	SE-6-5	78		90	90	84	84	72	67	80	79	77	77
76.6	72.0	79.3	106.3	110.8	W-2-2	SE-6-7	80		95	90	90	87	77	70	78	80		79
74.0	85.3	76.6	145.0	96.7	W-2-5	NE-2-2	78	87	95	89	92	86	80	70	80	80		77
77.2	78.0	76.8	121.9	85.0	W-2-7	NE-2-5	77	82	90	90	88	85	73	70	79	80		
78.0	77.5		112.5	107.9	W-4-2	NE-2-7	80	80	87	90		82	68	70	77	80		
79.0	76.3		117.7	106.0	W-4-5	NE-4-2	75	83	89	89		86	70	66	77	78		
73.5	77.0			106.8	W-4-7	NE-4-5	77	80	88	90		82	71	68	80	79		
74.0	80.5			105.6	W-6-2	NE-4-7		78	88	90	82	80	68	70	80	80		
75.5	79.2			116.0	W-6-5	NE-6-2			89	88	80	84	70	67	78	79		
77.5	74.0				W-6-7	NE-6-5			90	89	80	82	71	67	80	79		
77.6	76.7				SE-2-2	NE-6-7	96		88	89	88	80	70	69	79	79		
71.3	76.8				SE-2-5	TL-2	86		90		84		70		80			
74.7	77.5				SE-2-7	TL-5	76		91		84		72		79			
76.4	79.0				SE-4-2	TL-7	79		88		84		67		79			
70.7	80.0				SE-4-5		78		90		84		68		79			
75.0																		
75.5																		
77.3																		

C = center; W = west; SE = southeast; NE = northeast; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 2-AII. OVEN MOISTURE CONTENT DATA AT LA CHINA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA													
RAW DATA				ELEVATOR: LA CHINA			PARAMETER: OVEN MOISTURE CONTENT (% WET BASIS)						
					GRAIN SAMPLING INSIDE THE BIN								
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING	1ST MONTH	2ND MONTH	3RD MONTH	4TH MONTH	BIN UNLOADING POINT	TRUCK LOADING POINT
16.91	13.72	NO	NO	13.03	C-2	SE-4-7						12.21	12.17
13.61	14.57			12.73	C-5	SE-6-2						12.58	12.59
12.70	13.43			13.11	C-7	SE-6-5						12.52	12.24
12.46	14.72			13.69	W-2-2	SE-6-7						12.13	12.50
12.08	15.16			12.85	W-2-5	NE-2-2						11.49	12.32
13.19	13.68			12.93	W-2-7	NE-2-5							11.79
14.31	14.66			13.14	W-4-2	NE-2-7							12.13
14.26	13.56			13.21	W-4-5	NE-4-2							
15.51	12.84			13.60	W-4-7	NE-4-5							
13.59	13.69			13.12	W-6-2	NE-4-7							
13.28	11.78			12.56	W-6-5	NE-6-2							
13.77	13.75				W-6-7	NE-6-5							
13.07	13.34				SE-2-2	NE-6-7							
14.00					SE-2-5	TL-2	12.36	12.53	12.36	12.28	12.62		
14.23					SE-2-7	TL-5	12.47	12.61	12.32	12.15	12.17		
13.02					SE-4-2	TL-7	12.52	12.38	12.11	12.24	12.00		
13.87					SE-4-5								
13.32													
13.60													

C = center; W = west; SE = southeast; NE = northeast; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 3-AII. MOTOMCO MOISTURE CONTENT DATA AT LA CHINA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVTIES OF C.N.P., COSTA RICA																	
RAW DATA				ELEVATOR: LA CHINA				PARAMETER: MOTOMCO MOISTURE CONTENT (% WET BASIS)									
				GRAIN SAMPLING INSIDE THE BIN													
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
17.79	13.70	15.22	11.77	12.41	C-2	SE-4-7	12.34	12.63	11.70	12.06	13.13	12.59	12.84	12.77	14.13	13.34	12.42	12.56
13.34	14.49	14.78	12.20	12.77	C-5	SE-6-2	11.98		12.27	12.56	12.56	12.95	12.34	13.06	12.13	13.27	12.63	12.70
12.34	13.70	15.86	13.20	13.92	C-7	SE-6-5	12.20		12.05	12.48	12.13	12.87	12.42	13.42	12.20	13.27	12.56	12.77
11.77	15.29	14.04	13.92	14.85	W-2-2	SE-6-7	12.49		12.05	12.34	12.77	12.70	12.80	12.77	12.84	13.06	12.20	12.85
12.99	14.57	13.56	13.56	13.42	W-2-5	NE-2-2	12.56	11.98	11.98	12.05	12.24	12.80	12.05	12.77	12.84	12.77	11.91	12.35
14.14	13.70	13.42	13.49	13.49	W-2-7	NE-2-5	12.49	12.13	11.55	12.06	12.25	12.84	12.13	13.08	12.27	12.77		11.99
15.15	14.64		12.70	12.34	W-4-2	NE-2-7	12.27	12.05	12.34	11.98		12.63	13.20	12.56	13.49	12.66		12.49
14.93	13.13		12.99	13.27	W-4-5	NE-4-2	12.49	12.13	12.41	12.41		12.59	13.20	13.06	12.77	13.35		
16.29	13.20			13.85	W-4-7	NE-4-5	12.49	12.05	11.51	12.56		12.63	12.80	13.20	12.05	13.20		
13.70	13.63			12.63	W-6-2	NE-4-7		12.06	12.56	11.98	13.13	12.59	13.06	12.73	12.70	12.99		
15.21	12.06			12.84	W-6-5	NE-6-2			12.41	12.70	13.16	12.94	13.06	12.70	12.41	13.63		
15.14	13.35				W-6-7	NE-6-5			12.20	12.84	12.35	13.15	12.41	13.23	11.91	13.90		
15.86	14.35				SE-2-2	NE-6-7	12.92		12.34	12.34	12.77	13.20	12.63	13.20	13.63	13.83		
14.06					SE-2-5	TL-2	12.34	12.27	12.34	11.92	12.92	12.36	12.84	12.73	12.99	12.77		
14.57					SE-2-7	TL-5	12.70	11.98	11.84	11.99	12.59	12.32	12.56	12.87	12.48	12.42		
15.29					SE-4-2	TL-7	12.92	12.16	12.34	11.70	13.42	12.11	13.35	12.51	13.85	12.34		
13.92					SE-4-5		12.84		12.06		12.95		13.13		14.21			
14.21																		
13.78																		
13.85																		

C = center; W = west; SE = southeast; NE = northeast; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 4-AII. BULK DENSITY DATA AT LA CHINA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																		
RAW DATA				ELEVATOR: LA CHINA				PARAMETER: BULK DENSITY (Kg/HL)										
					GRAIN SAMPLING INSIDE THE BIN													
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
73.70	75.90	76.4	75.80	76.66	C-2	SE-4-7	76.16	75.76	74.23	75.50	74.06	76.06	74.10	75.80	74.30	75.26	74.77	74.47
78.10	69.06	74.8	75.33	75.73	C-5	SE-6-2	74.53		74.80	75.86	74.63	75.10	74.56	75.33	73.86	75.00	74.20	74.37
77.43	74.63	77.6	76.16	74.86	C-7	SE-6-5	75.23		75.93	76.03	77.20	76.00	76.46	76.03	75.26	75.56	74.37	75.07
76.26	73.93	74.7	74.56	75.26	W-2-2	SE-6-7	76.33		76.16	74.86	76.76	74.93	76.56	75.33	76.30	74.20	73.97	74.60
73.00	75.93	76.4	74.76	75.16	W-2-5	NE-2-2	76.60	76.10	75.73	77.33	76.06	76.90	76.00	76.50	76.26	76.03	73.93	75.03
74.46	73.66	75.7	76.26	76.53	W-2-7	NE-2-5	76.40	77.00	76.66	76.50	76.46	76.33	76.46	76.16	76.70	74.86		73.83
74.56	75.50		76.16	75.90	W-4-2	NE-2-7	76.63	75.66	74.33	75.73		76.06	77.93	75.76	76.23	75.83		74.10
75.46	74.90		75.63	75.76	W-4-5	NE-4-2	77.16	75.83	76.60	76.80		76.66	76.33	76.93	76.30	76.30		
73.73	76.00			75.86	W-4-7	NE-4-5	76.56	76.00	77.46	76.33		76.23	77.20	76.66	76.90	76.33		
75.00	75.83			76.50	W-6-2	NE-4-7		75.30	75.93	75.73	75.86	75.40	75.63	75.43	75.60	75.03		
75.50	77.90			75.53	W-6-5	NE-6-2			75.56	76.36	75.73	75.80	76.03	75.90	75.50	75.66		
75.10	76.60				W-6-7	NE-6-5			76.13	76.23	75.50	76.23	75.30	75.93	75.60	75.46		
75.83	74.40				SE-2-2	NE-6-7	75.13		76.36	74.76	76.63	75.30	76.23	74.66	75.36	75.03		
74.03					SE-2-5	TL-2	75.70		76.00	75.90	76.50	76.36	75.90	76.10	74.56	76.27		
74.73					SE-2-7	TL-5	75.80		75.80	75.80	76.10	76.16	76.23	76.13	75.93	76.07		
72.10					SE-4-2	TL-7	75.93		76.23	75.80	76.73	76.00	76.86	75.73	76.53	75.70		
76.16					SE-4-5		76.66		76.93		77.23		76.73		76.13			
75.40																		
76.36																		
75.40																		

C = center; W = west; SE = southeast; NE = northeast; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 5-AII. TRUE DENSITY DATA AT LA CHINA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																	
RAW DATA				ELEVATOR: LA CHINA				PARAMETER: TRUE DENSITY (gr/ml)									
					GRAIN SAMPLING INSIDE THE BIN												
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
1.30	1.27	NO	NO	1.30	C-2	SE-4-7	1.30	1.29									1.32	1.26
1.30	1.26			1.28	C-5	SE-6-2	1.27										1.31	1.31
1.29	1.26			1.28	C-7	SE-6-5	1.30										1.24	1.30
1.30	1.28			1.30	W-2-2	SE-6-7											1.29	1.32
1.25	1.29			1.30	W-2-5	NE-2-2											1.29	1.27
1.27	1.30			1.28	W-2-7	NE-2-5												1.29
1.27	1.28			1.28	W-4-2	NE-2-7	1.30											1.28
1.28	1.27			1.34	W-4-5	NE-4-2		1.28										
1.32	1.26			1.32	W-4-7	NE-4-5	1.31	1.29										
1.32	1.28			1.32	W-6-2	NE-4-7		1.30										
1.25	1.30			1.32	W-6-5	NE-6-2												
1.28	1.29				W-6-7	NE-6-5												
1.26	1.29				SE-2-2	NE-6-7												
1.25					SE-2-5	TL-2				1.28		1.27		1.28		1.27		
1.25					SE-2-7	TL-5				1.33		1.26		1.27		1.28		
1.27					SE-4-2	TL-7	1.28			1.31		1.26		1.28		1.27		
1.26					SE-4-5		1.34											
1.30																		
1.27																		
1.29																		

C = center; W = west; SE = southeast; NE = northeast; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 6-AII. IMPURITIES DATA AT LA CHINA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																		
RAW DATA				ELEVATOR: LA CHINA				PARAMETER: IMPURITIES* (% ON 500 GR SAMPLE)										
				GRAIN SAMPLING INSIDE THE BIN														
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
0.43	0.57	0.58	0.35	0.34	C-2	SE-4-7	5.10	1.04	3.68	1.24	6.35	1.06	5.44	0.86	1.50	0.65	0.89	1.74
0.40	0.51	0.80	0.57	0.32	C-5	SE-6-2	2.23		6.00	0.86	4.20	1.32	6.72	1.05	5.74	0.39	0.94	1.07
0.75	0.52	0.54	0.30	0.46	C-7	SE-6-5	2.20		0.77	1.32	1.44	0.56	5.15	0.46	1.12	0.50	2.24	0.83
1.38	0.46	0.46	0.70	0.50	W-2-2	SE-6-7	0.53		2.04	1.04	1.01	0.73	0.64	0.68	0.93	0.74	1.13	0.79
1.52	0.56	0.31	0.64	0.27	W-2-5	NE-2-2	0.28	1.10	1.86	1.95	1.53	1.84	1.11	1.58	1.40	1.15	2.09	0.79
0.86	0.68	0.96	0.27	0.43	W-2-7	NE-2-5	0.32	0.95	1.36	4.10	1.55	1.99	1.02	1.94	0.58	2.13		0.62
0.53	0.40		0.56	0.42	W-4-2	NE-2-7	0.57	3.53	0.46	3.90		1.60	0.28	2.47	0.29	1.12		0.38
1.46	1.10		0.78	0.45	W-4-5	NE-4-2	0.26	0.62	0.33	1.08		1.02	0.20	0.69	0.16	0.52		
0.57	0.34			0.57	W-4-7	NE-4-5	0.33	1.06	0.57	1.23		1.16	0.30	0.84	0.20	0.56		
0.54	0.39			0.38	W-6-2	NE-4-7		1.02	0.22	1.72	0.44	1.26	0.42	1.06	0.38	1.24		
0.47	0.30			0.54	W-6-5	NE-6-2			0.34	0.80	0.27	0.88	0.20	0.56	0.20	0.27		
0.64					W-6-7	NE-6-5			0.30	0.53	0.30	0.74	0.39	0.53	0.16	0.46		
0.82					SE-2-2	NE-6-7	0.64		3.30	0.77	2.88	0.83	1.91	0.75	0.95	0.47		
0.72					SE-2-5	TL-2	1.86		1.57	1.53	1.40	3.02	0.97	2.46	0.70	1.51		
0.64					SE-2-7	TL-5	1.68		1.74	1.79	1.34	2.12	0.92	1.00	0.51	1.48		
0.27					SE-4-2	TL-7	0.68		2.86	1.15	1.61	2.10	0.68	0.88	0.52	1.07		
0.44					SE-4-5		0.36		0.79		0.68		0.56		0.23			
0.66																		
0.83																		
0.48																		

C = center; W = west; SE = southeast; NE = northeast; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m
* 12/64 screen + large and small impurities

TABLE 7-AII. BROKENS DATA AT LA CHINA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																		
RAW DATA					ELEVATOR: LA CHINA				PARAMETER: BROKENS (% OVER 100 GR CLEAN GRAIN)									
					GRAIN SAMPLING INSIDE THE BIN													
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
0.46	1.53	1.17	0.57	0.49	C-2	SE-4-7	3.16	1.93	3.20	2.81	2.95	2.14	2.63	2.51	2.42	1.25	0.86	1.06
0.98	0.54	1.59	0.92	0.61	C-5	SE-6-2	2.46		4.70	2.14	3.03	1.36	3.13	2.33	4.01	1.44	0.52	1.31
1.07	0.50	2.60	0.71	1.59	C-7	SE-6-5	2.75		2.60	2.37	1.43	1.33	2.22	1.16	2.93	1.37	0.94	1.92
0.40	1.26	0.92	2.00	2.98	W-2-2	SE-6-7	1.94		1.86	2.09	1.76	1.56	1.55	1.66	2.57	1.33	2.14	1.33
1.96	1.33	0.66	1.60	2.12	W-2-5	NE-2-2	1.95	2.26	2.26	2.83	1.26	1.63	1.88	0.81	2.15	3.67	2.23	0.90
1.55	2.04	2.28	0.68	0.33	W-2-7	NE-2-5	1.63	1.13	2.09	1.43	1.44	1.80	1.46	1.94	1.49	2.66		1.87
1.18	1.48		1.12	1.63	W-4-2	NE-2-7	1.64	3.13	3.66	2.54		1.94	1.00	1.66	0.40	2.12		2.14
1.14	0.73		1.32	1.18	W-4-5	NE-4-2	1.03	2.63	5.06	2.29		1.43	0.83	1.07	0.37	1.53		
5.83	0.59			1.15	W-4-7	NE-4-5	2.06	1.46	1.46	2.43		1.49	1.78	1.05	0.95	1.43		
0.61	2.60			1.56	W-6-2	NE-4-7		2.45	2.06	2.46	1.46	1.26	1.25	1.63	0.84	1.70		
0.25	0.15			2.22	W-6-5	NE-6-2			1.28	1.83	1.06	2.37	1.39	1.33	0.46	0.99		
0.14	2.13				W-6-7	NE-6-5			1.91	1.78	1.30	1.88	1.67	1.34	0.92	0.64		
0.85	2.53				SE-2-2	NE-6-7	3.20		3.53	1.84	2.49	1.95	2.10	0.74	3.59	1.50		
1.22					SE-2-5	TL-2	3.11		3.60	1.34	1.53	2.57	1.20	1.28	1.97	1.97		
1.81					SE-2-7	TL-5	3.63		4.26	0.92	2.68	1.88	1.41	0.74	2.13	2.27		
1.69					SE-4-2	TL-7	2.39		1.88	2.07	1.75	1.80	2.32	1.05	1.18	1.17		
0.68					SE-4-5		1.03		1.53		1.18		1.19		0.94			
0.29																		
0.53																		
0.80																		

C = center; W = west; SE = southeast; NE = northeast; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 8-AII. DAMAGE BY INSECT DATA AT LA CHINA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																	
RAW DATA				ELEVATOR: LA CHINA				PARAMETER: DAMAGE BY INSECT (% OVER 100 GR CLEAN SAMPLE)									
				GRAIN SAMPLING INSIDE THE BIN													
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH	BIN UNLOADING POINT	TRUCK LOADING POINT
0.00	0.00	0.15	0.00	0.06	C-2	SE-4-7	0.00	0.30	0.20	0.10	0.47	0.26	0.35	0.36	0.57	0.68	0.23	1.07
0.23	0.00	0.00	0.25	0.27	C-5	SE-6-2	0.36		0.00	0.11	0.72	0.13	0.65	0.38	0.34	0.38	0.72	0.97
0.00	0.06	0.00	0.30	0.21	C-7	SE-6-5	0.14		0.26	0.00	0.17	0.23	0.43	0.08	0.22	0.13	0.91	0.50
0.33	0.13	0.00	0.31	0.00	W-2-2	SE-6-7	0.38		0.63	0.22	0.76	0.13	0.29	0.53	0.35	0.78	0.91	0.14
0.00	0.28	0.20	0.34	0.00	W-2-5	NE-2-2	0.20	0.20	0.28	0.33	2.24	0.20	1.35	0.28	1.05	0.10	0.70	0.27
0.29	0.17		0.00	0.26	W-2-7	NE-2-5	0.30	0.11	0.21	0.00	1.15	0.10	0.42	0.61	0.20	0.17		1.21
0.06	0.05		0.16	0.10	W-4-2	NE-2-7	0.15	0.33	0.00	0.51		0.26	0.22	0.54	0.16	0.26		1.06
0.07	0.24		0.10	0.13	W-4-5	NE-4-2	0.26	0.25	0.00	0.20		0.16	0.51	0.39	0.63	0.18		
0.06	0.25			0.07	W-4-7	NE-4-5	0.46	0.18	0.00	0.26		0.30	0.28	0.18	0.46	0.13		
0.18	0.35			0.20	W-6-2	NE-4-7		0.53	0.62	0.23	0.40	0.06	0.20	0.68	0.52	0.33		
0.00	0.10			0.00	W-6-5	NE-6-2			0.15	0.17	0.16	0.46	0.32	0.17	0.27	0.50		
0.00	0.03				W-6-7	NE-6-5			0.16	0.29	0.10	0.36	0.40	0.13	0.58	0.79		
0.00	0.25				SE-2-2	NE-6-7	0.00		0.00	0.17	0.79	0.54	0.62	0.43	0.38	0.70		
0.41					SE-2-5	TL-2	0.26		0.00	0.23	0.14	0.23	0.53	0.68	0.20	0.30		
0.06					SE-2-7	TL-5	0.10		0.06	0.48	0.43	0.06	0.56	0.78	0.26	0.00		
0.27					SE-4-2	TL-7	0.13		0.53	0.20	0.08	0.46	0.20	0.34	0.06	0.17		
0.24					SE-4-5		0.23		0.00		0.24		0.26		0.65			
0.45																		
0.30																		
0.07																		

C = center; W = west; SE = southeast; NE = northeast; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 9-AII. DAMAGE BY MOLDS DATA AT LA CHINA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																		
RAW DATA				ELEVATOR: LA CHINA					PARAMETER: DAMAGE BY MOLDS (% OVER 100 GRM CLEAN SAMPLE)									
					GRAIN SAMPLING INSIDE THE BIN													
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
3.28	0.27	1.60	0.83	0.81	C-2	SE-4-7	0.73	0.53	0.66	0.30	1.52	0.42	2.11	0.49	20.64	0.00	0.09	0.00
0.10	0.70	0.24	0.67	0.28	C-5	SE-6-2	0.23		0.86	1.00	1.11	0.00	1.54	1.20	0.99	0.20	0.08	0.10
0.06	0.47	0.24	0.98	0.05	C-7	SE-6-5	0.38		0.73	0.85	1.24	0.10	1.13	1.39	1.52	1.21	0.29	0.00
0.10	0.12	0.09	0.08	0.17	W-2-2	SE-6-7	0.71		0.65	0.87	0.71	0.13	0.22	0.99	0.59	0.57	0.18	0.10
0.25	0.07	0.99	0.08	0.08	W-2-5	NE-2-2	0.10	0.10	0.29	0.29	0.06	0.16	0.05	0.50	1.43	0.44	0.07	0.08
0.35	0.35	0.13	0.87	0.64	W-2-7	NE-2-5	0.06	0.20	2.18	1.56	0.50	0.00	0.92	1.00	1.16	0.91		0.13
0.20	0.31		0.15	0.13	W-4-2	NE-2-7	0.12	0.33	0.12	0.63		0.10	0.13	1.56	0.14	1.05		0.03
0.36	0.30		0.23	0.16	W-4-5	NE-4-2	0.40	0.03	0.11	0.06		0.00	0.00	0.58	0.05	0.00		
0.51	0.44			0.55	W-4-7	NE-4-5	0.20	0.10	0.70	0.23		0.28	1.06	0.38	0.17	0.00		
0.53	0.31			0.20	W-6-2	NE-4-7		0.10	0.05	0.30	0.00	0.00	1.31	0.82	0.16	0.00		
0.25	0.30			0.15	W-6-5	NE-6-2			0.23	0.35	0.26	0.06	1.20	0.81	0.00	0.06		
0.36	0.62				W-6-7	NE-6-5			0.00	0.39	0.13	0.10	1.47	0.23	0.29	0.00		
0.60					SE-2-2	NE-6-7	0.30		0.78	0.15	1.00	0.26	0.16	0.41	0.84	0.10		
0.08					SE-2-5	TL-2	1.06		0.08	0.26	1.20	0.30	0.28	0.00	0.44	0.18		
0.33					SE-2-7	TL-5	0.13		0.33	0.49	1.43	0.24	0.00	0.43	0.00	0.00		
0.38					SE-4-2	TL-7	0.23		0.29	0.49	0.75	0.15	1.48	0.13	0.03	0.07		
0.00					SE-4-5		0.43		0.04		1.17		1.42		0.28			
2.22																		
0.40																		
0.54																		
0.13																		

C = center; W = west; SE = southeast; NE = northeast; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 10-AII. AFLATOXINS DATA AT LA CHINA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA													
RAW DATA				ELEVATOR: LA CHINA			PARAMETER: AFLATOXINS (PPB)						
					GRAIN SAMPLING INSIDE THE BIN								
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING	1ST MONTH	2ND MONTH	3RD MONTH	4TH MONTH	BIN UNLOADING POINT	TRUCK LOADING POINT
625	65	NO	NO	220	C-2	SE-4-7						300(-)	NO
0	20			60	C-5	SE-6-2						30(-)	
29	0			13	C-7	SE-6-5						60(+)	
15	20			150	W-2-2	SE-6-7						29(-)	
32	0			50	W-2-5	NE-2-2						36(-)	
22	56			320	W-2-7	NE-2-5							
100	52			105	W-4-2	NE-2-7							
34	220			140	W-4-5	NE-4-2							
17	0			20	W-4-7	NE-4-5							
66	0			45	W-6-2	NE-4-7							
33	99			29	W-6-5	NE-6-2							
0	40				W-6-7	NE-6-5							
41	156				SE-2-2	NE-6-7							
0	5				SE-2-5	TL-2	160(-)	30(-)	50(-)	35(-)	125(+)		
5	0				SE-2-7	TL-5	50(-)	180(-)	125(+)	35(-)	70(-)		
20	121				SE-4-2	TL-7	23(-)	40(-)	70(+)	65(+)	40(-)		
0	0				SE-4-5								
0	1650												
750	0												
85	320												
15	50												

C = center; W = west: SE = southeast; NE = northeast: TL = total level; 2 = 2.1m; 4 = 4.2m: 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 11-AII. TEMPERATURE OATA AT TERRABA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																	
RAW DATA				ELEVATOR: TERRABA				PARAMETER: GRAIN TEMPERATURE (°F)									
				GRAIN SAMPLING INSIOE THE BIN													
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2NO MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOAOING POINT
76.66	82.33	83.46	138.31	134.25	C-2	SW-4-7	95		90	87	85	80	94	91	98	95	95.6	95.5
83.33	87.00	86.68	135.87	141.25	C-5	SW-6-2	92	90	90	87	84	80	96	89	98	92	94.5	94.8
88.00	85.66	87.66	142.25	137.50	C-7	SW-6-5	93	88	91	86	85	79	98	90	96	93	91.5	93.8
85.00	84.00	86.50	131.75	128.81	E-2-2	SW-6-7		90	88	84	82	78	92	90	94	95	95.0	92.0
85.00	86.66	85.50	129.15	124.40	E-2-5	NW-2-2			86	88	81	87	93	96	94	96		
86.00	84.00	83.37	127.85	125.13	E-2-7	NW-2-5			88	86	81	89	92	97	94	100		
88.00	84.50	85.43	128.30	122.43	E-4-2	NW-2-7	90		86	86	80	88	92	98	92	98		
85.00	82.00	84.56		131.06	E-4-5	NW-4-2	88	90	87	85	80	82	91	94	93	95		
86.00	89.33	85.60			E-4-7	NW-4-5	88	88	85	84	80	81	90	93	92	95		
84.00	81.50				E-6-2	NW-4-7	88	90	86	87	82	82	90	94	92	96		
84.83	88.00				E-6-5	NW-6-2	90	87	85	85	80	80	90	92	93	92		
85.50	82.50				E-6-7	NW-6-5	89	88	86	84	80	80	90	91	94	93		
86.66	82.00				SW-2-2	NW-6-7	90	89	89	84	84	81	94	92	99	93		
82.33	91.50				SW-2-5	TL-2	90		88		82		94		97			
84.50					SW-2-7	TL-5	90		89		83		96		94			
83.66					SW-4-2	TL-7			87		82		93		95			
87.00					SW-4-5				87		80		92		95			
85.00																		
85.00																		
85.33																		

C = center; E = east; SW = southwest; NW = northwest; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 12-AII. OVEN MOISTURE CONTENT DATA AT TERRABA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVTTIES OF C.N.P., COSTA RICA																		
RAW OATA				ELEVATOR: TERRABA					PARAMETER: OVEN MOISTURE CONTENT (% WET BASIS)									
					GRAIN SAMPLING INSIOE THE BIN													
HOPPER		AFTER CLEANING	AFTER ORYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2NO MONTH		3RD MONTH		4TH MONTH		BIN UNLOAOING POINT	TRUCK LOADING POINT
14.95	13.46	NO	NO	12.11	C-2	SW-4-7											11.64	11.64
13.59	12.61			11.80	C-5	SW-6-2											11.04	11.40
14.74	13.01			12.38	C-7	SW-6-5											11.42	11.23
13.72	12.72			13.27	E-2-2	SW-6-7											11.42	11.60
13.68	15.83			12.34	E-2-5	NW-2-2												
13.29	13.37			12.37	E-2-7	NW-2-5												
12.37	13.10			11.88	E-4-2	NW-2-7												
12.80	13.80				E-4-5	NW-4-2												
13.33	18.33				E-4-7	NW-4-5												
16.46	13.87				E-6-2	NW-4-7												
16.18	12.66				E-6-5	NW-6-2												
17.35	14.15				E-6-7	NW-6-5												
17.38	16.38				SW-2-2	NW-6-7												
12.93	13.15				SW-2-5	TL-2		11.68		11.58		11.59		11.89		11.84		
12.92					SW-2-7	TL-5		11.54		11.55		11.55		11.79		11.70		
12.97					SW-4-2	TL-7		11.16		10.96		11.09		11.17		11.34		
16.97					SW-4-5													
15.34																		
17.27																		
12.51																		

C = center; E = east; SW = southwest; NW = northwest; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 13-AII. MOTOMCO MOISTURE CONTENT DATA AT TERRABA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P.. COSTA RICA																		
RAW DATA				ELEVATOR: TERRABA				PARAMETER: MOTOMCO MOISTURE CONTENT (% WET BASIS)										
				GRAIN SAMPLING INSIDE THE BIN														
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
16.22	17.36	15.29	12.11	12.10	C-2	SW-4-7	10.48		11.05	10.77	11.63	11.12	11.91	11.70	11.55	11.34	11.63	12.20
16.57	14.35	14.35	12.96	12.99	C-5	SW-6-2	11.09	11.70	10.91	11.77	11.70	12.49	11.69	12.27	10.98	11.98	11.48	11.48
15.79	14.57	15.24	12.99	12.70	C-7	SW-6-5	10.26	11.55	10.33	11.52	10.84	11.98	10.84	11.98	10.34	11.55	11.98	11.41
14.86	17.58	16.80	13.85	13.92	E-2-2	SW-6-7		10.76	11.58	11.12	11.48	11.55	12.20	11.62	11.41	11.34	11.98	12.13
15.21	15.21	16.87	13.92	14.57	E-2-5	NW-2-2			11.51	11.41	11.41	12.34	12.20	12.84	11.34	12.13		
14.78	17.43	16.65	13.45	13.85	E-2-7	NW-2-5			11.01	11.05	10.48	11.34	11.84	11.55	10.98	11.05		
13.49	14.57	14.50	13.78	12.77	E-4-2	NW-2-7	10.84		11.70	10.48	11.91	10.34	12.48	10.84	11.48	10.34		
14.06	15.29	16.72		13.06	E-4-5	NW-4-2	11.55	11.77	11.58	11.34	11.48	11.41	12.34	12.20	10.91	11.63		
14.64	13.92	15.29			E-4-7	NW-4-5	11.05	11.84	11.34	11.19	10.98	11.34	11.70	11.69	11.41	11.05		
17.25	14.49				E-6-2	NW-4-7	11.41	10.62	11.70	11.05	11.70	10.55	12.63	11.20	11.84	10.98		
16.25	13.49				E-6-5	NW-6-2	11.05	12.05	11.55	11.70	11.69	11.77	12.63	12.27	11.70	11.84		
16.00	16.72				E-6-7	NW-6-5		11.55	11.55	11.70	11.48	11.48	11.98	12.49	11.55	11.70		
15.25	15.00				SW-2-2	NW-6-7	11.62	11.41	11.12	11.29	11.48	11.20	12.05	11.91	11.55	11.34		
17.75	14.28				SW-2-5	TL-2	11.26	11.34	11.19	11.34	11.63	11.59	12.06	12.56	11.27	11.55		
17.29	15.00				SW-2-7	TL-5	11.12	11.12	10.62	11.65	10.69	11.55	11.34	12.13	10.77	10.77		
16.86	17.94				SW-4-2	TL-7		10.76	11.05	11.34	11.55	11.09	11.98	11.77	11.70	11.27		
19.94	15.36				SW-4-5				11.34		11.34		11.62		11.41			
14.57	15.13																	
16.96																		
14.05																		

C = center; E = east; SW = southwest; NW = northwest; TL = total level; 2 = 2.1m: 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 14-AII. BULK DENSITY DATA AT TERRABA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																	
RAW DATA				ELEVATOR: TERRABA				PARAMETER: BULK DENSITY (KG/HL)									
				GRAIN SAMPLING INSIDE THE BIN													
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
76.60	76.20	76.86	76.40	75.56	C-2	SW-4-7	76.26		77.50	76.43	76.56	76.10	77.60	76.20	76.00	75.60	75.10	76.81
75.66	75.43	78.20	75.71	75.90	C-5	SW-6-2	76.46	76.80	76.43	77.00	76.36	76.50	76.46	76.13	75.96	76.23	75.50	75.96
74.96	76.60	76.53	74.30	75.56	C-7	SW-6-5	77.70	76.63	77.30	75.86	76.56	75.93	77.03	76.16	76.60	75.46	75.60	75.70
74.86	76.50	76.46	75.46	75.00	E-2-2	SW-6-7		76.76	77.50	75.13	77.10	75.90	76.96	75.60	76.13	74.90	75.60	74.70
74.70	74.96	76.10	77.63	75.80	E-2-5	NW-2-2			77.13	77.26	76.90	76.36	76.90	76.46	76.33	76.13		
75.86	76.23	75.26	75.40	72.36	E-2-7	NW-2-5			77.06	77.06	76.70	76.73	76.80	77.16	75.80	76.20		
75.63	75.56	76.43	77.90	75.33	E-4-2	NW-2-7	77.90		77.40	77.70	77.36	77.46	76.76	77.46	76.60	76.00		
75.03	75.60	76.96		76.13	E-4-5	NW-4-2	76.43	76.93	77.16	76.43	77.16	76.10	76.96	76.53	76.63	75.63		
76.40	75.00	76.96			E-4-7	NW-4-5	76.50	77.23	76.53	76.83	76.30	76.53	76.13	77.20	75.80	76.06		
74.96	76.76				E-62	NW-4-7	77.56	77.30	77.00	76.53	77.16	77.06	77.00	77.13	76.33	76.26		
75.56	75.30				E-6-5	NW-6-2	76.36	76.83	76.13	76.73	76.50	76.96	76.63	76.43	76.03	76.66		
74.90	74.10				E-6-7	NW-6-5	76.83	77.00	77.16	76.66	77.26	76.93	76.60	76.46	75.63	76.30		
74.20	75.93				SW-2-2	NW-6-7	77.40	76.86	75.30	76.60	76.46	76.70	76.60	76.13	75.80	75.63		
75.66	76.00				SW-2-5	TL-2	76.46	76.65	76.43	76.96	76.83	76.56	76.70	76.56	75.83	76.00		
74.86	77.26				SW-2-7	TL-5	77.03	76.53	76.33	76.83	76.56	76.63	76.60	76.63	76.43	76.26		
75.56	75.66				SW-4-2	TL-7		76.66	76.83	76.80	75.93	76.53	75.83	76.60	75.53	76.23		
74.50	77.60				SW-4-5				76.16		76.56		76.30		76.03			

C = center; E = east; SW = southwest; NW = northwest; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 15-AII. TRUE DENSITY DATA AT TERRABA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																		
RAW DATA				ELEVATOR: TERRABA					PARAMETER: TRUE DENSITY (GR/ML)									
					GRAIN SAMPLING INSIDE THE BIN													
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
1.29	1.32	1.32	1.28	1.25	C-2	SW-4-7	1.29										1.30	1.30
1.27	1.28	1.27	1.34	1.30	C-5	SW-6-2	1.25										1.30	1.29
1.32	1.30	1.28	1.33	1.31	C-7	SW-6-5	1.29										1.29	1.30
1.30	1.28	1.30	1.28	1.28	E-2-2	SW-6-7											1.28	1.29
1.30	1.29	1.29	1.33	1.33	E-2-5	NW-2-2												
1.32	1.28	1.33	1.28	1.29	E-2-7	NW-2-5												
1.28	1.27	1.28	1.31	1.33	E-4-2	NW-2-7												
1.27	1.30	1.30		1.29	E-4-5	NW-4-2												
1.30	1.30				E-4-7	NW-4-5												
1.32	1.28				E-6-2	NW-4-7												
1.32	1.29				E-6-5	NW-6-2												
1.28	1.29				E-6-7	NW-6-5												
1.27	1.30				SW-2-2	NW-6-7												
1.32	1.28				SW-2-5	TL-2		1.24		1.30		1.29		1.31		1.31		
1.30	1.32				SW-2-7	TL-5		1.27		1.29		1.30		1.26		1.30		
1.29	1.32				SW-4-2	TL-7		1.32		1.27		1.30		1.27		1.30		
					SW-4-5													

C = center; E = east; SW = southwest; NW = northwest; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 16-AII. IMPURITIES DATA AT TERRABA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																		
RAW DATA				ELEVATOR: TERRABA					PARAMETER: IMPURITIES (% OVER 500 GR SAMPLE)									
				GRAIN SAMPLING INSIDE THE BIN														
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
0.74	0.92	0.38	0.96	0.87	C-2	SW-4-7	6.14		2.28	0.62	1.36	0.87	0.89	049	2.00	1.51	0.91	0.37
0.60	0.82	0.43	0.60	0.81	C-5	SW-6-2	0.69	1.14	1.77	0.92	0.51	0.41	1.57	0.48	3.72	0.86	0.35	0.35
0.86	0.37	0.33	0.43	0.75	C-7	SW-6-5	3.50	0.74	1.60	0.42	0.73	0.56	1.47	0.36	3.20	0.78	0.72	0.50
0.49	0.56	0.40	0.33	0.80	E-2-2	SW-6-7		0.51	1.32	0.71	0.93	0.96	2.57	0.86	1.90	1.02	0.54	1.13
1.09	0.75	0.46	0.36	0.54	E-2-5	NW-2-2			2.09	2.17	1.06	3.93	0.97	2.53	1.90	5.55		
1.28	0.48	0.33	0.56	2.77	E-2-7	NW-2-5			1.18	0.92	1.66	3.40	2.01	2.20	2.22	5.24		
0.67	2.39	0.47	0.76	1.46	E-4-2	NW-2-7	2.40		1.16	0.54	0.63	2.06	0.92	1.69	0.88	5.98		
0.54	0.70	0.50		0.56	E-4-5	NW-4-2	1.02	2.58	0.47	0.49	0.79	1.20	0.76	1.00	1.18	1.05		
0.67	1.44	0.60			E-4-7	NW-4-5	2.43	1.68	0.82	0.58	0.70	0.66	1.12	0.72	0.51	1.00		
1.08	0.46				E-6-2	NW-4-7	0.60	1.70	0.52	0.28	0.44	0.33	0.84	0.36	0.65	0.98		
0.82	0.88				E-6-5	NW-6-2	1.19	0.89	0.73	0.44	0.54	0.70	0.68	0.47	0.77	0.72		
0.98	1.50				E-6-7	NW-6-5	0.60	0.64	0.54	0.39	0.50	0.50	0.60	0.40	0.73	0.75		
0.72	0.47				SW-2-2	NW-6-7	3.26	1.28	2.60	0.44	1.35	0.56	1.27	0.49	1.87	0.79		
0.78	0.44				SW-2-5	TL-2	1.32		0.80	1.80	1.73	0.90	1.64	1.85	2.46	1.92		
0.80	0.25				SW-2-7	TL-5	1.89		0.58	0.59	1.36	1.16	1.44	0.95	2.05	1.25		
	0.48				SW-4-2	TL-7			0.46	0.59	1.13	0.46	1.42	0.84	1.70	0.87		
	0.37				SW-4-5				0.80		0.66		0.47		1.42			
	0.50																	
	0.36																	

C = center; E = east; SW = southwest; NW = northwest; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 17-AII. BROKENS DATA AT TERRABA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																		
RAW DATA				ELEVATOR: TERRABA					PARAMETER: BROKENS (% OVER 100 GR CLEAN SAMPLE)									
				GRAIN SAMPLING INSIDE THE BIN														
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
1.40	1.70	2.93	2.73	3.23	C-2	SW-4-7	2.58		2.28	1.48	2.76	2.03	1.81	1.79	1.74	1.44	2.22	1.96
0.96	0.30	2.20	1.23	2.40	C-5	SW-6-2	1.71	0.55	3.05	1.34	2.71	1.38	2.38	0.69	2.27	1.50	1.36	3.69
2.20	1.23	1.70	2.00	1.66	C-7	SW-6-5	2.08	1.04	2.17	1.02	2.82	2.60	2.77	0.80	4.19	0.63	1.60	2.15
1.50	1.73	0.70	2.10	3.26	E-2-2	SW-6-7		1.83	1.44	2.00	2.15	2.34	2.09	1.26	1.17	0.84	1.70	4.50
2.26	1.40	0.86	1.50	1.50	E-2-5	NW-2-2			1.44	2.56	2.53	2.71	1.31	1.26	1.25	3.41		
4.90	6.76	0.40	2.10	1.16	E-2-7	NW-2-5			2.05	2.78	2.06	2.93	1.91	2.78	1.45	2.56		
2.76	0.46	1.93	0.80	1.30	E-4-2	NW-2-7	1.24		113	3.18	1.75	2.50	1.15	2.92	1.23	2.31		
0.97	6.20	1.70		2.00	E-4-5	NW-4-2	1.16	1.78	1.22	1.80	1.92	2.43	1.84	1.92	1.96	2.61		
2.73	0.16	0.83			E-4-7	NW-4-5	1.53	1.76	1.77	2.41	2.53	2.23	1.71	2.03	1.98	2.36		
0.60	0.73				E-6-2	NW-4-7	0.88	1.60	0.57	1.43	1.10	1.88	0.48	1.20	0.46	1.86		
1.91	2.26				E-6-5	NW-6-2	1.51	1.05	1.16	1.35	1.87	1.36	1.26	1.55	1.29	0.46		
1.50	0.70				E-6-7	NW-6-5	1.45	1.29	1.06	1.94	1.26	1.01	1.04	1.30	1.32	0.90		
0.70	0.16				SW-2-2	NW-6-7	2.63	1.56	2.33	1.10	2.76	1.53	1.71	1.54	4.35	0.68		
4.93	2.13				SW-2-5	TL-2	1.94		2.12	1.43	2.93	1.70	1.76	1.50	1.73	1.34		
1.80	0.53				SW-2-7	TL-5	2.54		1.24	1.60	2.73	1.86	1.42	2.63	1.82	1.26		
1.39	0.13				SW-4-2	TL-7			1.65	1.53	1.16	1.33	1.72	1.82	1.23	0.72		
	0.85				SW-4-5				1.96		2.84		2.30		1.37			
	0.20																	

C = center; E = east; SW = southwest; NW = northwest; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 18-AII. OAMAGE BY INSECT OATA AT TERRABA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																		
RAW OATA				ELEVATOR: TERRABA				PARAMETER: DAMAGE BY INSECT (% OVER 100 GR CLEAN SAMPLE)										
				GRAIN SAMPLING INSIDE THE BIN														
HOPPER		AFTER CLEANING	AFTER ORYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
0.23	0.10	0.40	0.00	0.00	C-2	SW-4-7	0.00		0.00	0.30	0.33	0.50	0.47	0.15	0.47	0.35	0.22	0.06
0.26	0.00	0.33	1.00	0.06	C-5	SW-6-2	0.04	0.20	0.00	0.61	0.55	0.36	0.93	0.24	0.23	0.20	0.06	0.30
0.42	0.00	0.26	0.00	0.00	C-7	SW-6-5	0.11	0.00	0.00	0.13	0.13	0.38	0.40	1.14	0.10	0.79	0.13	0.40
0.36	0.00	0.00	0.33	0.13	E-2-2	SW-6-7		0.06	0.80	0.28	0.00	0.51	0.11	0.60	0.61	0.44	0.00	0.13
0.16	0.00	0.26	0.28	0.00	E-2-5	NW-2-2			0.26	0.29	0.15	0.00	0.00	0.00	0.04	0.48		
0.43	0.10	0.93	0.00	0.20	E-2-7	NW-2-5			0.02	0.40	0.06	0.00	0.00	0.14	0.14	0.28		
0.60	0.00	0.10	0.00	0.13	E-4-2	NW-2-7	0.20		0.14	0.04	0.06	0.07	0.13	0.07	0.38	0.59		
0.63	0.26	0.00		0.20	E-4-5	NW-4-2	0.12	0.43	0.00	0.30	0.21	0.18	0.14	0.07	0.57	0.27		
0.03	0.00	0.00			E-4-7	NW-4-5	0.27	0.00	0.00	0.00	0.00	0.23	0.10	0.14	0.43	0.38		
0.13	0.06				E-6-2	NW-4-7	0.12	0.00	0.00	0.36	0.32	0.37	0.20	0.31	0.34	0.26		
0.06					E-6-5	NW-6-2	0.07	0.00	0.00	0.05	0.32	0.25	0.61	0.25	0.22	0.62		
0.00					E-6-7	NW-6-5	0.00	0.13	0.00	0.48	0.29	0.46	0.37	0.17	0.75	0.39		
0.00					SW-2-2	NW-6-7	0.00	0.06	0.22	0.10	0.30	0.28	0.70	0.25	0.38	0.22		
0.20					SW-2-5	TL-2	0.13		0.57	0.13	0.40	0.26	0.51	0.28	0.35	0.20		
0.43					SW-2-7	TL-5	0.00		0.44	0.13	0.06	0.06	0.43	0.35	0.32	0.25		
0.00					SW-4-2	TL-7			0.78	0.00	0.06	0.16	0.00	0.04	0.18	0.27		
0.20					SW-4-5				0.04		0.00		0.00		0.26			
0.10																		
0.10																		
0.00																		
0.16																		
0.10																		
0.00																		

C = center; E = east; SW = southwest; NW = northwest; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 19-AII. DAMAGE BY MOLD DATA AT TERRABA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA																	
RAW DATA				ELEVATOR: TERRABA				PARAMETER: DAMAGE BY MOLD (% OVER 100 GR CLEAN SAMPLE)									
				GRAIN SAMPLING INSIDE THE BIN													
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING		1ST MONTH		2ND MONTH		3RD MONTH		4TH MONTH		BIN UNLOADING POINT	TRUCK LOADING POINT
0.78	0.06	0.93	0.00	0.13	C-2	SW-4-7	0.66		0.27	0.58	0.13	0.16	0.30	0.66	0.00	0.00	0.00	0.06
1.33	0.40	0.90	0.80	0.73	C-5	SW-6-2	0.53	1.39	0.07	0.27	0.08	0.00	0.10	0.18	0.09	0.10	0.00	0.00
1.23	0.00	0.96	0.66	0.73	C-7	SW-6-5	1.07	0.15	0.20	0.16	0.03	0.11	0.00	0.46	0.04	0.00	0.00	0.00
0.43	0.13	0.60	1.53	0.90	E-2-2	SW-6-7		0.53	0.24	0.33	0.00	0.16	0.51	0.23	0.08	0.00	0.11	0.00
0.76	0.00	0.33	0.10	0.06	E-2-5	NW-2-2			0.58	0.16	0.00	0.11	0.78	0.56	0.07	0.00		
0.90	0.00	0.76	0.30	1.03	E-2-7	NW-2-5			0.49	0.10	0.13	0.00	0.94	0.83	0.00	0.08		
0.90	0.26	0.10	0.73	1.16	E-4-2	NW-2-7	0.27		0.55	0.20	0.00	0.24	0.92	0.87	0.06	0.05		
1.46	0.43	0.26		0.26	E-4-5	NW-4-2	0.38	0.54	0.11	0.30	0.10	0.30	0.98	0.45	0.07	0.00		
0.50	0.56	0.83			E-4-7	NW-4-5	0.60	0.36	0.43	0.42	0.10	0.10	0.65	0.85	0.15	0.06		
0.00	0.56				E-6-2	NW-4-7	0.41	0.55	0.65	0.00	0.09	0.13	0.10	0.54	0.50	0.00		
0.80	1.10				E-6-5	NW-6-2	0.57	0.62	0.16	0.67	0.20	0.13	0.00	1.07	0.00	0.04		
0.74	0.53				E-6-7	NW-6-5	0.58	0.32	0.00	0.61	0.00	0.16	0.23	0.46	0.00	0.00		
6.46	0.43				SW-2-2	NW-6-7	0.54	0.70	0.86	0.00	0.10	0.13	0.13	0.84	0.00	0.00		
0.50	1.26				SW-2-5	TL-2	0.62		0.96	0.00	0.06	0.10	0.00	1.23	0.00	0.00		
1.13	0.23				SW-2-7	TL-5	0.64		1.18	0.00	0.06	0.00	0.40	1.75	0.07	0.00		
0.80	0.93				SW-4-2	TL-7			1.63	0.00	0.00	0.10	0.57	0.91	0.00	0.00		
2.50					SW-4-5				0.49		0.00		0.87		0.00			
0.50																		
0.10																		

C = center; E = east; SW = southwest; NW = northwest; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

TABLE 20-AII. AFLATOXINS DATA AT TERRABA FACILITY

POST-HARVEST WHITE CORN LOSSES IN SOME ACTIVITIES OF C.N.P., COSTA RICA													
RAW DATA			ELEVATOR: TERRABA				PARAMETER: AFLATOXINS (PPB)						
					GRAIN SAMPLING INSIDE THE BIN								
HOPPER		AFTER CLEANING	AFTER DRYING	BIN FILLING POINT	SAMPLE LOCATION		AFTER FILLING	1ST MONTH	2ND MONTH	3RD MONTH	4TH MONTH	BIN UNLOADING POINT	TRUCK LOADING POINT
190	60	NO	NO	30(-)	C-2	SW-4-7						45(+)	NO
230	95			35(-)	C-5	SW-6-2						25(-)	
100	250			225(+)	C-7	SW-6-5						25(-)	
0	0			95(-)	E-2-2	SW-6-7						30(-)	
0	80			49(-)	E-2-5	NW-2-2							
12	120			50(-)	E-2-7	NW-2-5							
45	105			26(-)	E-4-2	NW-2-7							
5	0				E-4-5	NW-4-2							
50					E-4-7	NW-4-5							
0					E-6-2	NW-4-7							
160					E-6-5	NW-6-2							
27					E-6-7	NW-6-5							
31					SW-2-2	NW-6-7							
0					SW-2-5	TL-2	50(+)	42(-)	115(+)	85(+)	50(-)		
165					SW-2-7	TL-5	24(+)	37(-)	30(+)	35(+)	45(-)		
225					SW-4-2	TL-7	24(+)	31(-)	29(-)	31(-)	30(-)		
5					SW-4-5								
5													
370													
10													

C = center; E = east; SW = southwest; NW = northwest; TL = total level; 2 = 2.1m; 4 = 4.2m; 5 = 4.6m; 6 = 6.3m; 7 = 7.0m

APPENDIX III

ANALYSIS OF VARIOUS PARAMETERS EXAMINED

TABLE 1-AIII. IN-BIN AVERAGE TEMP VARIATIONS IN FARENHEIT OURING THE STORAGE PERIOO AT "LA CHINA"

ELEVATOR "LA CHINA" , SAN JOAQUIN OE FLORES , HEREOIA

FEBRUARY (initial cond.)	MARCH 1st Mo	APRIL 2nd Mo	MAY 3rd Mo	JUNE 4th Mo	ENV	LOC	LEVEL	OIST	RAD
96	100	90	83	77	1	1	1	0	1
80	95	90	77	78	1	2	1	1	1
80	87		68	77	1	3	1	2	1
	88	82	68	80	1	4	1	3	1
96	88	88	70	79	1	5	1	1	2
79	88	84	67	79	1	6	1	2	2
	90	86	67	80	1	7	1	3	2
87	89	86	70	80	1	8	1	1	3
83	89	86	66	78	1	9	1	2	3
	88	84	67	79	1	10	1	3	3
80	91	88	75	80	1	11	2	0	1
87	89	86	70	80	1	12	2	1	1
75	89		70	77	1	13	2	2	1
	89	80	70	78	1	14	2	3	1
86	90	84	70	79	1	15	2	1	2
78	90	84	68	79	1	16	2	2	2
	90	84	67	79	1	17	2	3	2
82	90	85	70	80	1	18	2	1	3
80	90	82	68	79	1	19	2	2	3
	89	82	67	79	1	20	2	3	3
78	90	84	72	80	1	21	3	0	1
77	90	88	73	79	1	22	3	1	1
77	89		71	80	1	23	3	2	1
	90	80	71	80	1	24	3	3	1
76	91	84	72	79	1	25	3	1	2
80	91	84	70	80	1	26	3	2	2
	90	87	70	80	1	27	3	3	2
80	90	82	70	80	1	28	3	1	3
78	90	80	70	80	1	29	3	2	3
	89	80	69	79	1	30	3	3	3

TABLE 2-AIII. IN-BIN TEMP VARIATIONS IN FARENHEIT DURING THE STORAGE PERIOD AT "LA CHINA"

	AVERAGE AMBIENT TEMP	LEVEL 1	LEVEL 2	LEVEL 3	TOTAL AVERAGE
FEBRUARY	72	86	81	78	82
MARCH	75	90	90	90	90
APRIL	73	86	84	83	84
MAY	72	70	70	71	70
JUNE	79	79	79	80	79

TABLE 3-AIII. IH-BIN AVERAGE TEMP VARIATIONS IN FARENHEIT DURING THE STORAGE PERIOD AT "LA CHINA"

MOHTNLY AVERAGES BY LEVEL BY RADIUS AT LA CHIHA

LEVEL 1		LEVEL 2		LEVEL 3	
RADIUS 1		RADIUS 1		RADIUS 1	
FEBRUARY	85	FEBRUARY	81	FEBRUARY	77
MARCH	93	MARCH	90	MARCN	90
APRIL	87	APRIL	85	APRIL	84
MAY	74	MAY	71	MAY	72
JUNE	78	JUNE	79	JUHE	80

LEVEL 1		LEVEL 2		LEVEL 3	
RADIUS 2		RADIUS 2		RADIUS 2	
FEBRUARY	88	FEBRUARY	82	FEBRUARY	78
MARCN	89	MARCH	90	MARCH	91
APRIL	86	APRIL	84	APRIL	85
MAY	68	MAY	68	MAY	71
JUNE	79	JUNE	79	JUNE	80

LEVEL 1		LEVEL 2		LEVEL 3	
RADIUS 3		RADIUS 3		RADIUS 3	
FEBRUARY	85	FEBRUARY	81	FEBRUARY	79
MARCN	89	MARCN	90	MARCH	90
APRIL	85	APRIL	83	APRIL	81
MAY	68	MAY	68	MAY	70
JUHE	79	JUHE	79	JUNE	80

TABLE 4-AIII. IN-BIN AVERAGE TEMP VARIATIONS IN FARENHEIT DURING THE STORAGE PERIOD AT "LA CHINA"

MONTHLY AVERAGES BY LEVELS BY DISTANCES AT LA CHINA

DIST 1	LEVEL 1	LEVEL 2	LEVEL 3
FEBRUARY	88	85	78
MARCH	91	90	90
APRIL	88	85	85
MAY	72	70	72
JUNE	79	80	79

DIST 2	LEVEL 1	LEVEL 2	LEVEL 3
FEBRUARY	81	78	78
MARCH	88	90	90
APRIL	85	83	82
MAY	67	69	70
JUNE	78	78	80

DIST 3	LEVEL 1	LEVEL 2	LEVEL 3
FEBRUARY			
MARCH	89	89	90
APRIL	84	82	82
MAY	67	68	70
JUNE	80	79	80

TABLE 5-AIII. IN-BIN AVERAGE TEMP VARIATIONS IN FARENHEIT DURING THE STORAGE PERIOD AT "LA CHINA"

TOTAL AVERAGES BY RADIUS FOR THE WHOLE BIN

	RADIUS 1	RADIUS 2	RADIUS 3
FEBRUARY	81	83	82
MARCH	91	90	89
APRIL	85	85	83
MAY	72	69	69
JUNE	79	79	79

TOTAL AVERAGES BY DISTANCE FOR THE WHOLE BIN

	DIST 1	DIST 2	DIST 3
FEBRUARY	83	79	
MARCH	90	89	90
APRIL	86	83	83
MAY	71	69	68
JUNE	79	79	79

TABLE 6-AIII. IN-BIN MOISTURE VARIATIONS IN PERCENTAGE DURING THE STORAGE PERIOD AT "LA CHINA"

ELEVATOR "LA CHINA" , SAN JOAQUIN DE FLORES , HEREDIA

FEBRUARY	MARCH	APRIL	MAY	JUNE	ENV	LOC	LEVEL	DIST	RAD
(initial cond.)	1st Mo	2nd Mo	3rd Mo	4th Mo					
12.34	11.70	13.13	12.84	14.13	1	1	1	0	1
12.49	12.05	12.77	12.80	12.84	1	2	1	1	1
12.27	12.34		13.20	13.49	1	3	1	2	1
	12.56	13.13	13.06	12.70	1	4	1	3	1
12.92	12.34	12.77	12.63	13.63	1	5	1	1	2
12.92	12.34	13.42	13.35	13.85	1	6	1	2	2
	12.56	12.95	13.06	13.27	1	7	1	3	2
11.98	12.05	12.80	12.77	12.77	1	8	1	1	3
12.13	12.41	12.59	13.06	13.35	1	9	1	2	3
	12.70	12.94	12.70	13.63	1	10	1	3	3
11.98	12.27	12.56	12.34	12.13	1	11	2	0	1
12.56	11.98	12.24	12.05	12.84	1	12	2	1	1
12.49	12.41		13.20	12.77	1	13	2	2	1
	12.41	13.16	13.06	12.41	1	14	2	3	1
12.34	12.34	12.92	12.84	12.99	1	15	2	1	2
12.84	12.06	12.95	13.13	14.21	1	16	2	2	2
	12.48	12.87	13.42	13.27	1	17	2	3	2
12.13	12.06	12.84	13.08	12.77	1	18	2	1	3
12.05	12.56	12.63	13.20	13.20	1	19	2	2	3
	12.84	13.15	13.23	13.90	1	20	2	3	3
12.20	12.05	12.13	12.42	12.20	1	21	3	0	1
12.49	11.55	12.25	12.13	12.27	1	22	3	1	1
12.49	11.51		12.80	12.05	1	23	3	2	1
	12.20	12.35	12.41	11.91	1	24	3	3	1
12.70	11.84	12.59	12.56	12.48	1	25	3	1	2
12.63	12.06	12.59	12.77	13.34	1	26	3	2	2
	12.34	12.70	12.77	13.06	1	27	3	3	2
12.05	11.98	12.63	12.56	12.66	1	28	3	1	3
12.06	11.98	12.59	12.73	12.99	1	29	3	2	3
	12.34	13.20	13.20	13.83	1	30	3	3	3

TABLE 7-AIII. IN-BIN MOISTURE VARIATIONS IN PERCENTAGE DURING THE STORAGE PERIOD AT "LA CHINA"

	AVERAGE AMBIENT REL HUM	LEVEL 1	LEVEL 2	LEVEL 3	TOTAL AVERAGE
FEBRUARY	68	12.44	12.34	12.37	12.38
MARCN	69	12.31	12.34	11.99	12.21
APRIL	70	12.94	12.81	12.55	12.77
MAY	79	12.95	12.96	12.64	12.85
JUNE	84	13.37	13.05	12.68	13.03

TABLE 8-AIII. IN-BIN MOISTURE VARIATIONS IN PERCENTAGE DURING THE STORAGE PERIOD AT "LA CHINA"

MONTHLY AVERAGES BY LEVEL BY RADIUS AT LA CHINA

LEVEL 1 RADIUS 1		LEVEL 2 RADIUS 1		LEVEL 3 RADIUS 1	
FEBRUARY	12.37	FEBRUARY	12.34	FEBRUARY	12.39
MARCH	12.16	MARCH	12.27	MARCH	11.83
APRIL	13.01	APRIL	12.65	APRIL	12.24
MAY	12.98	MAY	12.66	MAY	12.44
JUNE	13.29	JUNE	12.54	JUNE	12.11

LEVEL 1 RADIUS 2		LEVEL 2 RADIUS 2		LEVEL 3 RADIUS 2	
FEBRUARY	12.92	FEBRUARY	12.59	FEBRUARY	12.67
MARCH	12.41	MARCH	12.29	MARCH	12.08
APRIL	13.05	APRIL	12.91	APRIL	12.63
MAY	13.01	MAY	13.13	MAY	12.70
JUNE	13.58	JUNE	13.49	JUNE	12.96

LEVEL 1 RADIUS 3		LEVEL 2 RADIUS 3		LEVEL 3 RADIUS 3	
FEBRUARY	12.06	FEBRUARY	12.09	FEBRUARY	12.06
MARCH	12.39	MARCH	12.49	MARCH	12.10
APRIL	12.78	APRIL	12.87	APRIL	12.81
MAY	12.84	MAY	13.17	MAY	12.83
JUNE	13.25	JUNE	13.29	JUNE	13.16

TABLE 9-AIII. IN-BIN MOISTURE VARIATIONS IN PERCENTAGE DURING THE STORAGE PERIOD AT "LA CHINA"

MONTHLY AVERAGES BY LEVELS BY DISTANCES AT LA CHINA

DIST 1	LEVEL 1	LEVEL 2	LEVEL 3
FEBRUARY	12.46	12.34	12.41
MARCH	12.15	12.13	11.79
APRIL	12.78	12.67	12.49
MAY	12.73	12.66	12.42
JUNE	13.08	12.87	12.47

DIST 2	LEVEL 1	LEVEL 2	LEVEL 3
FEBRUARY	12.44	12.46	12.39
MARCH	12.36	12.34	11.85
APRIL	13.01	12.79	12.59
MAY	13.20	13.18	12.77
JUNE	13.56	13.39	12.79

DIST 3	LEVEL 1	LEVEL 2	LEVEL 3
FEBRUARY			
MARCH	12.61	12.58	12.29
APRIL	13.01	13.06	12.75
MAY	12.94	13.24	12.79
JUNE	13.20	13.19	12.93

TABLE 10-AIII. IN-BIN MOISTURE VARIATIONS IN PERCENTAGE DURING THE STORAGE PERIOD AT "LA CHINA"

TOTAL AVERAGES BY RADIUS FOR THE WHOLE BIN

	RADIUS 1	RADIUS 2	RADIUS 3
FEBRUARY	12.36	12.72	12.06
MARCH	12.08	12.26	12.32
APRIL	12.63	12.86	12.81
MAY	12.69	12.95	12.95
JUNE	12.64	13.34	13.23

TOTAL AVERAGES BY DISTANCE FOR THE WHOLE BIN

	DIST 1	DIST 2	DIST 3
FEBRUARY	12.40	12.43	
MARCH	12.02	12.18	12.49
APRIL	12.64	12.80	12.94
MAY	12.60	13.04	12.95
JUNE	12.80	13.25	13.11

TABLE 11-AIII. IN-BIN DAMAGE BY INSECT VARIATIONS IN PERCENTAGE DURING THE STORAGE PERIOD AT "LA CHINA"

ELEVATOR "LA CHINA" , SAN JOAQUIN DE FLORES , HEREDIA

FEBRUARY (initial cond.)	MARCH 1st Mo	APRIL 2nd Mo	MAY 3rd Mo	JUNE 4th Mo	ENV	LOC	LEVEL	DIST	RAD
0.00	0.20	0.47	0.35	0.57	1	1	1	0	1
0.38	0.63	0.76	0.29	0.35	1	2	1	1	1
0.15	0.00		0.22	0.16	1	3	1	2	1
	0.62	0.40	0.20	0.52	1	4	1	3	1
0.00	0.00	0.79	0.62	0.38	1	5	1	1	2
0.13	0.53	0.08	0.20	0.06	1	6	1	2	2
	0.11	0.13	0.38	0.38	1	7	1	3	2
0.20	0.33	0.20	0.28	0.10	1	8	1	1	3
0.25	0.20	0.16	0.39	0.18	1	9	1	2	3
	0.17	0.46	0.17	0.50	1	10	1	3	3
0.36	0.00	0.72	0.65	0.34	1	11	2	0	1
0.20	0.28	2.24	1.35	1.05	1	12	2	1	1
0.26	0.00		0.51	0.63	1	13	2	2	1
	0.15	0.16	0.32	0.27	1	14	2	3	1
0.26	0.00	0.14	0.53	0.20	1	15	2	1	2
0.23	0.00	0.24	0.26	0.65	1	16	2	2	2
	0.00	0.23	0.08	0.13	1	17	2	3	2
0.11	0.00	0.10	0.61	0.17	1	18	2	1	3
0.18	0.26	0.30	0.18	0.13	1	19	2	2	3
	0.29	0.36	0.13	0.58	1	20	2	3	3
0.14	0.26	0.17	0.43	0.22	1	21	3	0	1
0.30	0.21	1.15	0.42	0.20	1	22	3	1	1
0.46	0.00		0.28	0.46	1	23	3	2	1
	0.16	0.10	0.40	0.58	1	24	3	3	1
0.10	0.06	0.43	0.56	0.26	1	25	3	1	2
0.30	0.10	0.26	0.36	0.68	1	26	3	2	2
	0.22	0.13	0.53	0.78	1	27	3	3	2
0.33	0.51	0.26	0.54	0.26	1	28	3	1	3
0.53	0.23	0.06	0.68	0.33	1	29	3	2	3
	0.17	0.54	0.43	0.70	1	30	3	3	3

TABLE 12-AIII. IN-BIN DAMAGE BY INSECT VARIATIONS IN PERCENTAGE DURING THE STORAGE AT "LA CHINA"

	AVERAGE AMBIENT TEMP	LEVEL 1	LEVEL 2	LEVEL 3	TOTAL AVERAGE
FEBRUARY	72	0.16	0.23	0.31	0.23
MARCH	75	0.28	0.10	0.19	0.19
APRIL	73	0.38	0.50	0.32	0.41
MAY	72	0.31	0.46	0.46	0.41
JUNE	79	0.32	0.42	0.45	0.39

TABLE 13-AIII. IN-BIN AVERAGE TEMP VARIATIONS IN FARENNEIT DURING THE STORAGE PERIOD AT "TERRABA"

ELEVATOR "TERRABA", PALMAR NORTE , PUNTARENAS

MARCN (initial condit)	APRIL 1st Mo	MAY 2nd Mo	JUNE 3rd Mo	JULY 4th Mo	ENV	LOC	LEVEL	DIST	RAD
95	90	85	94	98	2	1	1	0	1
	88	82	92	94	2	2	1	1	1
90	86	80	92	92	2	3	1	2	1
88	86	82	90	92	2	4	1	3	1
90	89	84	94	99	2	5	1	1	2
	87	82	93	95	2	6	1	2	2
90	87	80	89	92	2	7	1	3	2
	88	87	96	96	2	8	1	1	3
90	85	82	94	95	2	9	1	2	3
87	85	80	92	92	2	10	1	3	3
92	90	84	96	98	2	11	2	0	1
	86	81	93	94	2	12	2	1	1
88	87	80	91	93	2	13	2	2	1
90	85	80	90	93	2	14	2	3	1
90	88	82	94	97	2	15	2	1	2
	87	80	92	95	2	16	2	2	2
88	86	79	90	93	2	17	2	3	2
	86	89	97	100	2	18	2	1	3
88	84	81	93	95	2	19	2	2	3
88	84	80	91	93	2	20	2	3	3
93	91	85	98	96	2	21	3	0	1
	88	81	92	94	2	22	3	1	1
88	85	80	90	92	2	23	3	2	1
89	86	80	90	94	2	24	3	3	1
90	89	83	96	94	2	25	3	1	2
	87	80	91	95	2	26	3	2	2
90	84	78	90	95	2	27	3	3	2
	86	88	98	98	2	28	3	1	3
90	87	82	94	96	2	29	3	2	3
89	84	81	92	93	2	30	3	3	3

TABLE 14 AIII. IN-BIN TEMP VARIATIONS IN FARENHEIT DURING THE STORAGE PERIOD AT "TERRABA"

	AVERAGE AMBIENT TEMP	LEVEL 1	LEVEL 2	LEVEL 3	TOTAL AVERAGE
MARCH	82	90	89	90	90
APRIL	82	87	86	87	87
MAY	81	82	82	82	82
JUNE	80	93	93	93	93
JULY	80	95	95	95	95

TABLE 15-AIII. IN-BIN AVERAGE TEMP VARIATIONS IN FARENHEIT DURING THE STORAGE PERIOD AT "TERRABA"

MONTNLY AVERAGES BY LEVEL BY RADIUS AT TERRABA

	LEVEL 1 RADIUS 1		LEVEL 2 RADIUS 1		LEVEL 3 RADIUS 1
MARCH	91	MARCH	90	MARCH	90
APRIL	88	APRIL	87	APRIL	88
MAY	82	MAY	81	MAY	82
JUNE	92	JUNE	93	JUNE	93
JULY	94	JULY	95	JULY	94

	LEVEL 1 RADIUS 2		LEVEL 2 RADIUS 2		LEVEL 3 RADIUS 2
MARCH	90	MARCH	89	MARCH	90
APRIL	88	APRIL	87	APRIL	87
MAY	82	MAY	80	MAY	80
JUNE	92	JUNE	92	JUNE	92
JULY	95	JULY	95	JULY	95

	LEVEL 1 RADIUS 3		LEVEL 2 RADIUS 3		LEVEL 3 RADIUS 3
MARCH	89	MARCH	88	MARCH	90
APRIL	86	APRIL	85	APRIL	86
MAY	83	MAY	83	MAY	84
JUNE	89	JUNE	94	JUNE	95
JULY	94	JULY	96	JULY	96

TABLE 16-AIII. IN-BIN AVERAGE TEMP VARIATIONS IN FARENNEIT DURING TNE STORAGE PERIOD AT "TERRABA"

MONTNLY AVERAGES BY LEVELS BY DISTANCES AT TERRABA

LEVEL 1		LEVEL 2		LEVEL 3	
DIST 1		DIST 1		DIST 1	
MARCN	90	MARCN	90	MARCN	90
APRIL	88	APRIL	87	APRIL	88
MAY	84	MAY	84	MAY	84
JUNE	94	JUNE	95	JUNE	95
JULY	96	JULY	97	JULY	95

LEVEL 1		LEVEL 2		LEVEL 3	
DIST 2		DIST 2		DIST 2	
MARCH	90	MARCN	88	MARCH	89
APRIL	86	APRIL	86	APRIL	86
MAY	81	MAY	80	MAY	81
JUNE	93	JUNE	92	JUNE	92
JULY	94	JULY	94	JULY	94

LEVEL 1		LEVEL 2		LEVEL 3	
DIST 3		DIST 3		DIST 3	
MARCN	88	MARCN	89	MARCN	89
APRIL	86	APRIL	85	APRIL	85
MAY	81	MAY	80	MAY	80
JUNE	90	JUNE	92	JUNE	91
JULY	92	JULY	93	JULY	94

TABLE 17-AIII. IN-BIN AVERAGE TEMP VARIATIONS IN FARENHEIT DURING THE STORAGE PERIOD AT "TERRABA"

TOTAL AVERAGES BY RADIUS FOR THE WHOLE BIN

	RADIUS 1	RADIUS 2	RADIUS 3
MARCH	90	90	89
APRIL	87	87	85
MAY	82	81	83
JUNE	92	92	92
JULY	94	95	95

TOTAL AVERAGES BY DISTANCE FOR THE WHOLE BIN

	DIST 1	DIST 2	DIST 3
MARCH	90	89	89
APRIL	88	86	85
MAY	84	81	80
JUNE	95	92	91
JULY	96	94	93

TABLE 18-AIII. IN-BIN MOISTURE VARIATIONS IN PERCENTAGE DURING THE STORAGE PERIOD AT "TERRABA"

ELEVATOR "TERRABA", PALMAR NORTE , PUNTARENAS

MARCH (initial condit)	APRIL 1st Mo	MAY 2nd Mo	JUNE 3rd Mo	JULY 4th Mo	ENV	LOC	LEVEL	DIST	RAD
10.48	11.05	11.63	11.91	11.55	2	1	1	0	1
	11.58	11.48	12.20	11.41	2	2	1	1	1
10.48	11.70	11.91	12.48	11.48	2	3	1	2	1
11.41	11.70	11.70	12.63	11.84	2	4	1	3	1
11.62	11.12	11.48	12.05	11.55	2	5	1	1	2
	11.05	11.55	11.98	11.70	2	6	1	2	2
11.70	11.77	12.49	12.27	11.98	2	7	1	3	2
	11.41	12.34	12.84	12.13	2	8	1	1	3
11.77	11.34	11.41	12.20	11.63	2	9	1	2	3
12.05	11.70	11.77	12.27	11.84	2	10	1	3	3
11.09	10.91	11.70	11.69	10.98	2	11	2	0	1
	11.51	11.41	12.20	11.34	2	12	2	1	1
11.55	11.58	11.48	12.34	10.91	2	13	2	2	1
11.05	11.55	11.69	12.63	11.70	2	14	2	3	1
11.26	11.19	11.63	12.06	11.27	2	15	2	1	2
	11.34	11.34	11.62	11.41	2	16	2	2	2
11.55	11.52	11.98	11.98	11.55	2	17	2	3	2
	11.05	11.34	11.55	11.05	2	18	2	1	3
11.84	11.19	11.34	11.69	11.05	2	19	2	2	3
11.55	11.70	11.48	12.49	11.70	2	20	2	3	3
10.26	10.33	10.84	10.84	10.34	2	21	3	0	1
	11.01	10.48	11.84	10.98	2	22	3	1	1
11.05	11.34	10.98	11.70	11.41	2	23	3	2	1
	11.55	11.48	11.98	11.55	2	24	3	3	1
11.12	10.62	10.69	11.34	10.77	2	25	3	1	2
	10.77	11.12	11.70	11.34	2	26	3	2	2
10.76	11.12	11.55	11.62	11.34	2	27	3	3	2
	10.48	10.34	10.84	10.34	2	28	3	1	3
10.62	11.05	10.55	11.20	10.98	2	29	3	2	3
11.41	11.29	11.20	11.91	11.34	2	30	3	3	3

TABLE 19-AIII. IN-BIN MOISTURE VARIATIONS IN PERCENTAGE DURING THE STORAGE PERIOD AT "TERRABA"

	AVERAGE AMBIENT REL HUM	LEVEL 1	LEVEL 2	LEVEL 3	TOTAL AVERAGE
MARCH	83	11.36	11.41	10.87	11.23
APRIL	86	11.44	11.35	10.96	11.25
MAY	90	11.78	11.54	10.92	11.41
JUNE	89	12.28	12.03	11.50	11.94
JULY	89	11.71	11.30	11.04	11.35

TABLE 20-AIII. IN-BIN MOISTURE VARIATIONS IN PERCENTAGE DURING TNE STORAGE PERIOD AT "TERRABA"

MONTNLY AVERAGES BY LEVEL BY RADIUS AT TERRABA

LEVEL 1 RADIUS 1		LEVEL 2 RADIUS 1		LEVEL 3 RADIUS 1	
MARCH	10.79	MARCN	11.23	MARCN	10.66
APRIL	11.51	APRIL	11.39	APRIL	11.06
MAY	11.68	MAY	11.57	MAY	10.95
JUNE	12.31	JUNE	12.22	JUNE	11.59
JULY	11.57	JULY	11.23	JULY	11.07

LEVEL 1 RADIUS 2		LEVEL 2 RADIUS 2		LEVEL 3 RADIUS 2	
MARCH	11.66	MARCH	11.41	MARCN	10.94
APRIL	11.31	APRIL	11.35	APRIL	10.84
MAY	11.84	MAY	11.65	MAY	11.12
JUNE	12.10	JUNE	11.89	JUNE	11.55
JULY	11.74	JULY	11.41	JULY	11.15

LEVEL 1 RADIUS 3		LEVEL 2 RADIUS 3		LEVEL 3 RADIUS 3	
MARCN	11.91	MARCN	11.70	MARCN	11.02
APRIL	11.48	APRIL	11.31	APRIL	10.94
MAY	11.84	MAY	11.39	MAY	10.70
JUNE	12.14	JUNE	11.91	JUNE	11.32
JULY	11.87	JULY	11.27	JULY	10.89

TABLE 21-AIII. IN-BIN MOISTURE VARIATIONS IN PERCENTAGE DURING THE STORAGE PERIOD AT "TERRABA"

MONTHLY AVERAGES BY LEVELS BY DISTANCES AT TERRABA

	LEVEL 1 DIST 1		LEVEL 2 DIST 1		LEVEL 3 DIST 1
MARCH	11.62	MARCH	11.26	MARCH	11.12
APRIL	11.37	APRIL	11.25	APRIL	10.70
MAY	11.77	MAY	11.46	MAY	10.50
JUNE	12.36	JUNE	11.94	JUNE	11.34
JULY	11.70	JULY	11.22	JULY	10.70

	LEVEL 1 DIST 2		LEVEL 2 DIST 2		LEVEL 3 DIST 2
MARCH	11.13	MARCH	11.70	MARCH	10.84
APRIL	11.36	APRIL	11.37	APRIL	11.05
MAY	11.62	MAY	11.39	MAY	10.88
JUNE	12.22	JUNE	11.88	JUNE	11.53
JULY	11.60	JULY	11.12	JULY	11.24

	LEVEL 1 DIST 3		LEVEL 2 DIST 3		LEVEL 3 DIST 3
MARCH	11.72	MARCH	11.38	MARCH	11.09
APRIL	11.72	APRIL	11.59	APRIL	11.32
MAY	11.99	MAY	11.72	MAY	11.41
JUNE	12.39	JUNE	12.05	JUNE	11.84
JULY	11.89	JULY	11.65	JULY	11.41

TABLE 22-AIII. IN-BIN MOISTURE VARIATIONS IN PERCENTAGE DURING THE STORAGE PERIOD AT "TERRABA"

TOTAL AVERAGES BY RADIUS FOR THE WHOLE BIN

	RADIUS 1	RADIUS 2	RADIUS 3
MARCH	10.89	11.33	11.54
APRIL	11.31	11.16	11.24
MAY	11.40	11.54	11.30
JUNE	12.03	11.84	11.78
JULY	11.29	11.43	11.33

TOTAL AVERAGES BY DISTANCE FOR THE WHOLE BIN

	DIST 1	DIST 2	DIST 3
MARCH	11.33	11.21	11.39
APRIL	11.11	11.26	11.54
MAY	11.24	11.29	11.70
JUNE	11.88	11.88	12.09
JULY	11.20	11.32	11.65

TABLE 23-AIII. IN-BIN DAMAGE BY INSECT VARIATIONS IN PERCENTAGE DURING THE STORAGE PERIOD AT "TERRABA"

ELEVATOR "TERRABA", PALMAR NORTE , PUNTARENAS

MARCH (initial condit)	APRIL 1st Mo	MAY 2nd Mo	JUNE 3rd Mo	JULY 4th Mo	ENV	LOC	LEVEL	DIST	RAD
0.00	0.00	0.33	0.47	0.47	2	1	1	0	1
	0.80	0.00	0.11	0.61	2	2	1	1	1
0.20	0.14	0.06	0.13	0.38	2	3	1	2	1
0.12	0.00	0.32	0.20	0.34	2	4	1	3	1
0.00	0.22	0.30	0.70	0.38	2	5	1	1	2
	0.78	0.06		0.18	2	6	1	2	2
0.20	0.61	0.36	0.24	0.20	2	7	1	3	2
	0.29	0.00	0.00	0.48	2	8	1	1	3
0.43	0.30	0.18	0.07	0.27	2	9	1	2	3
0.00	0.05	0.25	0.25	0.62	2	10	1	3	3
0.04	0.00	0.55	0.93	0.23	2	11	2	0	1
	0.26	0.15	0.00	0.04	2	12	2	1	1
0.12	0.00	0.21	0.14	0.57	2	13	2	2	1
0.07	0.00	0.32	0.61	0.22	2	14	2	3	1
0.13	0.55	0.40	0.51	0.35	2	15	2	1	2
	0.04	0.00	0.00	0.26	2	16	2	2	2
0.00	0.13	0.38	1.14	0.79	2	17	2	3	2
	0.40	0.00	0.14	0.28	2	18	2	1	3
0.00	0.00	0.23	0.14	0.38	2	19	2	2	3
0.13	0.48	0.46	0.17	0.39	2	20	2	3	3
0.11	0.00	0.13	0.40	0.10	2	21	3	0	1
	0.02	0.06	0.00	0.14	2	22	3	1	1
0.27	0.00	0.00	0.10	0.43	2	23	3	2	1
0.00	0.00	0.29	0.37	0.75	2	24	3	3	1
0.00	0.44	0.06	0.43	0.32	2	25	3	1	2
	0.30	0.50	0.15	0.35	2	26	3	2	2
0.06	0.28	0.51	0.60	0.44	2	27	3	3	2
	0.04	0.07	0.07	0.59	2	28	3	1	3
0.00	0.36	0.37	0.31	0.26	2	29	3	2	3
0.06	0.10	0.28	0.25	0.22	2	30	3	3	3

TABLE 24-AIII. IN-BIN DAMAGE BY INSECT VARIATIONS IN PERCENTAGE DURING THE STORAGE AT "TERRABA"

	AVERAGE AMBIENT TEMP	LEVEL 1	LEVEL 2	LEVEL 3	TOTAL AVERAGE
MARCH	82	0.14	0.07	0.07	0.09
APRIL	82	0.32	0.19	0.15	0.22
MAY	81	0.19	0.27	0.23	0.23
JUNE	80	0.24	0.38	0.27	0.30
JULY	80	0.39	0.35	0.36	0.37

APPENDIX IV

THERMAL EFFICIENCY CALCULATIONS

APPENDIX IV

THERMAL EFFICIENCY CALCULATIONS

The following formula from Chang (1977) was used for the thermal efficiency.

$$TE = \frac{DM \times DC \times HVP \times (GM1 - GM2)}{\dfrac{H}{E1} + \dfrac{CONT \times HP}{E2 + E3}}$$

where

TE = thermal efficiency (decimal)

DM = dry matter content (lb/bu), corn = 47.32 lb/bu,
milo = 48.16 lb/bu

DC = dryer capacity (bu/hr)

HVP = heat of vaporization of water from grain (BTU/lb)

GM1, GM2 = initial and final moisture contents of grain (dry basis decimal)

H = energy to heat the air (BTU/hr)

E1 = efficiency of fuel consumption (decimal)

CONT = constant of conversion factor (0.7457 x 3412.4)

HP = fan and metering horse power (HP)

E2 = overall efficiency of fan and motor system (decimal)

E3 = efficiency of heat exchange system (decimal)

Case of the Mathews dryer, Model 900E, drying white corn at the La China plant with diesel fuel (tube axial type fan)

$$TE = \frac{47.32 * DC * HVP * (GM1 - GM2)}{\frac{H}{0.8} + \frac{(0.7458 \times 3412.4) * HP}{0.65 * 1}}$$

Case of the Berico dryer, Model 940 E, drying white corn at the Terraba plant with diesel fuel (forward curved centrifugal fan)

$$TE = \frac{47.32 * DC * HVP * (GM1 - GM2)}{\frac{H}{0.8} + \frac{(0.7457 * 3412.4) * HP}{0.5 * 1}}$$

Case of the Kan-Sun dryer, model drying milo at the Gary Gilbert elevator in Clay Center, Kansas, with natural gas (forward curved centrifugal fan)

$$TE = \frac{48.16 \quad DC \quad HVP * (GM1 - GM2)}{\frac{H}{0.85} + \frac{(0.7457 * 3412.4) * HP}{0.5 * 1}}$$

APPENDIX V

COMPUTER OUTPUTS SUMMARY

APPENDIX V

Data from the computer outputs corresponding to two of the five models tested are included here in table form. The intention of the models was to identify linear and/or quadratic trends in variations of the grain parameters analyzed during the storage period inside the bin. Table 1-AV shows the results of model number 2 that refers to the effects of the environment, the level, and the distance (and their interactions) in the trends followed by the data collected, leaving the observations over the radii as the error term due to the lack of replications of the storage bins. Table 2-AV describes the results of model number 3 which refers to the effects of the environment, the level, and the radiusi (and their interactions) in the trends followed by the data collected, leaving the observations over the distances as the error term due to lack of replication of the storage bins. With both models, similar conclusions were established, such as the clear effect of the environment and the radius in the trends followed by the grain temperature and Motomco moisture content data. The summary of the conclusions derived from the tables enclosed in this Appendix is shown on pages 84 and 85 of this thesis.

In the tables that follow, this nomenclature was used:

CL: linear component	LEV: level
CQ: quadratic component	MOIST: moisture
DF: degrees of freedom	MOT: Motomco
DIST: distance	RAD: radius
ENV: environment	VAR: variations

TABLE 1-AV. MODEL NO. 2, ENVIRONMENT-LEVEL-DISTANCE.

I. Using data on 5 months (initial condition and 4 more months)

	TEMPERATURE VARIATIONS (54 observations)				MOT MOIST CONTENT VAR (60 observations)				INSECT DAMAGE VAR (60 observations)			
ENV*LEV*DIST	DF	CL	DF	CQ	DF	CL	DF	CQ	DF	CL	DF	CQ
ENV	1	0.0001	1	0.0001	1	0.0007	1	0.0148	1	0.5532	1	0.7318
LEV	2	0.1126	2	0.6698	2	0.0012	2	0.4512	2	0.5021	2	0.6676
DIST	2	0.4095	2	0.8358	3	0.1652	3	0.6012	3	0.5841	3	0.0376
ENV*LEV	2	0.0682	2	0.9754	2	0.3880	2	0.6735	2	0.9168	2	0.8308
ENV*DIST	1	0.2191	1	0.9109	2	0.0198	2	0.6200	2	0.9876	2	0.8400
LEV*DIST	4	0.8480	4	0.6059	6	0.0181	6	0.8738	6	0.7744	6	0.9787
ENV*LEV*DIST	2	0.3555	2	0.9499	4	0.1493	4	0.7246	4	0.7018	4	0.8385
DF MODEL	14		14		20		20		20		20	
DF ERROR	18		18		17		17		17		17	

TABLE 1-AV. MODEL NO. 2, ENVIRONMENT-LEVEL-DISTANCE (Continued)

II. Using data on 4 months (ignoring initial condition)

	TEMPERATURE VARIATIONS (54 observations)				MOT MOIST CONTENT VAR (60 observations)				INSECT DAMAGE VAR (60 observations)			
ENV*LEV*DIST	DF	CL	DF	CQ	DF	CL	DF	CQ	DF	CL	DF	CQ
ENV	1	0.0001	1	0.0001	1	0.0001	1	0.0011	1	0.7705	1	0.2238
LEV	2	0.1734	2	0.2669	2	0.0039	2	0.4624	2	0.5361	2	0.0281
DIST	2	0.9873	2	0.0014	3	0.1178	3	0.3625	3	0.1771	3	0.0372
ENV*LEV	2	0.5585	2	0.5766	2	0.4712	2	0.2560	2	0.5621	2	0.9271
ENV*DIST	2	0.3202	2	0.4406	3	0.0745	3	0.7855	3	0.9681	3	0.0006
LEV*DIST	4	0.5084	4	0.9201	6	0.0488	6	0.9048	6	0.5899	6	0.6728
ENV*LEV*DIST	4	0.5905	4	0.5646	6	0.1741	6	0.9549	6	0.2191	6	0.9866
DF MODEL	17		17		23		23		23		23	
DF ERROR	33		33		33		33		32		32	

TABLE 2-AV. MODEL NO. 3, ENVIRONMENT-LEVEL-RADIUS.

I. Using data on 5 months (initial condition and 4 more months)

	TEMPERATURE VARIATIONS (54 observations)				MOT MOIST CONTENT VAR (60 observations)				INSECT DAMAGE VAR (60 observations)			
ENV*LEV*RAD	DF	CL	DF	CQ	DF	CL	DF	CQ	DF	CL	DF	CQ
ENV	1	0.0001	1	0.0001	1	0.0022	1	0.0007	1	0.4205	1	0.2967
LEV	2	0.0792	2	0.1279	2	0.0708	2	0.5111	2	0.1801	2	0.6786
RAD	2	0.7223	2	0.0440	2	0.9011	2	0.2512	2	0.2053	2	0.3454
ENV*LEV	2	0.0940	2	0.1663	2	0.3472	2	0.8310	2	0.9700	2	0.6735
ENV*RAD	2	0.4276	2	0.0653	2	0.0376	2	0.0077	2	0.7848	2	0.0192
LEV*RAD	4	0.6768	4	0.0473	4	0.1340	4	0.9867	4	0.7167	4	0.2060
ENV*LEV*RAD	4	0.7687	4	0.0898	4	0.8750	4	0.8353	4	0.8145	4	0.5096
DF MODEL	17		17		17		17		17		17	
DF ERROR	15		15		20		20		20		20	

TABLE 2-AV. MODEL NO. 3, ENVIRONMENT-LEVEL-RADIUS (Continued)

II. Using data on 4 months (ignoring initial condition)

	TEMPERATURE VARIATIONS (54 observations)				MOT MOIST CONTENT VAR (60 observations)				INSECT DAMAGE VAR (60 observations)			
ENV*LEV*RAD	DF	CL	DF	CQ	DF	CL	DF	CQ	DF	CL	DF	CQ
ENV	1	0.0001	1	0.0001	1	0.0001	1	0.0013	1	0.9152	1	0.0645
LEV	2	0.0830	2	0.2606	2	0.0902	2	0.4208	2	0.2317	2	0.1729
RAD	2	0.0157	2	0.1860	2	0.0193	2	0.2138	2	0.7867	2	0.1855
ENV*LEV	2	0.6046	2	0.5758	2	0.7432	2	0.0944	2	0.6000	2	0.8577
ENV*RAD	2	0.1102	2	0.0008	2	0.2793	2	0.6866	2	0.2056	2	0.6300
LEV*RAD	4	0.6609	4	0.9440	4	0.7303	4	0.9216	4	0.7292	4	0.1453
ENV*LEV*RAD	4	0.7449	4	0.8850	4	0.1974	4	0.6582	4	0.6550	4	0.9140
DF MODEL	17		17		17		17		17		17	
DF ERROR	33		33		39		39		38		38	

EVALUATION OF GRAIN LOSSES AND GRAIN DRYING PERFORMANCE AT LARGE GRAIN STORAGE AND HANDLING FACILITIES IN A DEVELOPING COUNTRY (SOME CNP OPERATIONS IN COSTA RICA)

by

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AN ABSTRACT OF A THESIS

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ABSTRACT

The research dealt with a study of the grain quality changes and loss assessment at tbe Consejo Nacional de Producción (CNP) grain handling and storage facilities in Costa Rica. The main objective after the grain loss assessment was to develop strategies to reduce grain losses. The facilities involved were the La China and the Térraba plants. Other tests on grain drying efficiency of clean and unclean corn (in Costa Rica) and milo (in Kansas) gave some data to judge the cleaning and drying operations in the elevators involved. The study required 1,800 MT of white corn from the 1987 dry season crop; CNP handling, storage, and laboratory facilities; the CIGRAS laboratory; CNP light and heavy transportation; and more than 900 complete grain quality analyses. The parameters measured were the grain weight, temperature, moisture content, density, impurities, broken kernels, damage by insects and molds, and aflatoxin level. Samples were taken during normal conditioning operations at the receiving hopper, after cleaning, after drying, at the bin filling point, after the bin filling process, monthly during the 4-month storage period, and during the grain unloading process from the bin. The grain surface level inside the bin was also recorded every month.

The results obtained after the statistical analysis showed statistically significant differences during the storage period for the La China plant in oven moisture content, damage by insects, bulk density, impurities, and grain temperature. At the Térraba plant, statistically significant changes were noticed only in grain temperature. The direct dry matter loss calculated in the La China plant was 1.68 percent and the volumetric wet grain loss was 1.38 percent. The direct dry matter loss

calculated in the Térraba plant was 0.32 percent and the volumetric wet grain loss was 0.38 percent. The study of the in-bin variations of grain temperature and moisture content during the storage period showed important temperature differentials as a result of the lack of a cooling process for the grain after drying in both plants. In both elevators, heating processes related to insect activity which the fumigations were not able to control, took place. A statistical analysis using the SAS program was applied to the in-bin variation data on temperature, moisture content, and insect damage to identify linear or quadratic trends in the variations of the parameters mentioned. The volumetric method of grain loss estimation during storage introduced in this study can be used in normal CNP grain storage operations. In general dry matter losses calculated are insignificant in normal grain handling operations, especially under tropical conditions. However, grain handling and storage practices at CNP can be further improved. The drying and cleaning performance tests showed that the drying of the unclean grain lots required more energy per pound of water evaporated (37 percent in the La China plant, 18 percent in the Térraba plant, and 15 percent in the Gary Gilbert elevator) than the drying of the clean grain lots. The importance of grain cleanliness in the in-plant grain handling was also shown.

The study was based on the dry season crop. Thus, quality changes and grain losses experienced should be considered as the lower values during the overall year-round operation. Therefore, unless a similar type of study with the wet season crop is conducted in the future, the overall situation on grain quality changes and grain loss in CNP operations cannot be truly assessed.